Strategy Development Pilot Study of Sleep-Restricted Operators Using Small Satellites with Displays

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INTRODUCTION: Sleep restriction may lead to decreased performance and increased accidents and errors. SPHERES, a small satellite testbed, was used to examine the effects of sleep restriction and situation awareness (SA) aids on a simulation of satellite operations.

METHODS: Subjects ($N = 8$) were trained on SPHERES, then, in a randomized order cross-over design, had 3 d of sufficient sleep (SS) or 3 d of sleep restriction (SR) before a testing session. Subjects controlled two SPHERES satellites in a space debris avoidance scenario. Dependent measures included survival time, area covered by the satellites, and satellite motion perception.

RESULTS: There were significant interaction effects of sleep protocol Order (SS or SR first) and sleep Condition (SS or SR) on survival time and area covered. Post hoc tests showed longer survival time for the second testing session if the Order was SS first (Mean = 56.1 s, Median = 44.0 s) as compared to SR first (Mean = 42.7 s, Median = 33.5 s). SS-first subjects received benefit from added SA cues of the augmented display in perceiving the satellite motion.

DISCUSSION: These data support that learning in a well-rested state may support development of appropriate strategies for better performance. Subjects that were SS during the first session were better able to use added SA cues provided by the augmentation and may have then developed a better mental model of the task and the system. This pilot study suggests that training guidelines for operating multiple robotic assets should permit appropriate rest before and after training to assist in mental model development and task performance.

KEYWORDS: sleep restriction, augmented reality, supervisory control, space debris.

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Operations in space by both government and commercial organizations require a large degree of preparation to safely and effectively explore humankind's last remaining frontier. While artificial intelligence and automation will progressively play a larger role in space operations, humans will remain involved in space operations for the foreseeable future.[13,26] Human supervised control of multiple robotic assets is also of interest in unmanned air and ground vehicles to optimize manpower and human-system performance.[3,7,30]

The space debris environment is highly volatile and the long-term forecast is for increasing space debris.[18] Human operators of space satellites need to control these assets while avoiding collisions with debris or other on-orbit assets. Yet these future operators are part of a culture that is experiencing sleep loss and its effects more often.[8,14] Sleep is important in learning new material, assisting in skill development to complete a task,[28,32] and therefore later performance of tasks.

Sleep loss, a reduction in the hours of sleep from the recommended levels, may occur due to sleep deprivation, sleep restriction, or sleep disruption.[1,23] Sleep restriction is a reduction in sleep duration over multiple nights and is associated with cognitive dysfunction comparable to measures after total sleep deprivation.[1] Sleep loss has been linked to performance decrements from reduced response time, reduced learning, decreased short-term recall of working memory, microsleeps, and increased commission and omission errors,[9] as well as

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increased accidents and errors.[3,31] For example, Smyth et al.[25] found extended wakefulness from physician overnight shifts led to decrements in attentional accuracy and Lo et al.[19] found restricted sleep led to decrements in sustained attention, speed of processing, and subjective alertness. Maquet et al.[20] observed that regional brain activity during rapid-eye-movement (REM) sleep is influenced by training on a task, highlighting that procedural memories are processed during REM sleep. Thus, there is strong evidence that sleep loss can affect the ability to implement procedures and develop strategy. Even stimulant countermeasures cannot fully reverse some of the higher level cognitive function degradation with sleep deprivation.[16] Unfortunately, humans' perception of sleepiness does not match their measured task performance degradation.[1,4,31] Multiple types of fatigue countermeasures are used by the aviation industry to mitigate risk.[6] Sleep loss is also prevalent in astronauts.[2]

Situation awareness (SA) is an important component for performing complex tasks. Endsley[10] defines three levels of SA: perception of the elements, comprehension of their meaning, and projection into the future. These levels build upon each other, with comprehension being a synthesis of the perceived elements with the user's mental model, and projection being the use of the updated mental model to estimate future states for determining an action response. SA requires high levels of cognitive functioning. Sleep loss can influence an individual's 1) ability to attain the levels of SA, 2) decision making, and 3) performance on a task.[10] In addition, under sleep loss or food deprivation conditions, people can overestimate their own SA, compared with the assessment of an expert.[21]

The relationship between SA and performance is task dependent. Higher SA will increase the probability of higher performance but cannot guarantee it.[10] Currently it is difficult for space analysts to perform anomaly assessment of the asset (i.e., satellite) using the current tools due to SA limitations in the control and display human-system interfaces.[13] SA aids, such as augmented displays that provide additional SA cues, may reduce the effort needed to achieve sufficient SA and enable appropriate human decision making, action selection, and operational success.

Many studies in the literature examine the effect of sleep using psychological tests designed to probe one particular cognitive process. This study extends the literature by investigating a complex task in which all three elements of SA are required to be active while using real satellite hardware, which increases the simulation fidelity. A ground-based simulated environment was used that incorporated a scenario in which the operator must avoid collisions among two small satellites and simulated debris while still prioritizing a region in space (e.g., simulating a desired orbital position). Good performance was defined as: 1) having a long survival time (i.e., the time from the start of the task until either a collision or the end of the task); 2) minimizing movement of the bounding box around the satellite motion; and 3) having good immediate recall of satellite state (i.e., position and direction of motion). The purpose of this study was to assess: 1) the effect of sleep Condition (sufficient sleep vs. sleep restriction) in operators controlling two small satellites; and 2) how augmented displays may mitigate any sleep Condition effects on performance on this task and SA. This study hypothesized that there would be an effect of sleep Condition and display on 1) performance, and 2) SA (e.g., the understanding of the satellites' state).

METHODS

Subjects

This study was approved by MIT's Committee on the Use of Humans as Experimental Subjects and subjects provided written informed consent. Consent was given by 10 subjects and 8 completed the protocol; 2 withdrew without completing any of the protocol due to scheduling conflicts. Of those completing the study, four men and four women had an average age of 23 yr (range 20–26; SD = 2.7 yr). Study inclusion criteria were: 1) age 18–29 yr, 2) average nightly sleep duration of 6–9.5 h, 3) no sleeping disorders, 4) no use of any illegal drugs or sleep altering medication, and 5) no excessive consumption of substances that could alter sleep (e.g., more than three cups' worth of coffee per day or more than three drinks' worth of alcohol on work nights). These eligibility criteria were assessed through self-report. Age was limited for this pilot study as sleep requirements vary by age.[22] Prior to each test session, eligibility was reviewed. Subjects were instructed to: 1) be in bed 9 h on rest (sufficient sleep) nights, 3.5–4.5 h on sleep restricted nights, and at least 6 h on other nights; and 2) not consume caffeine or alcohol on the day of an in-lab test. Subjects were compensated for participation in the study.

Equipment

The study took place at the Synchronized Position Hold, Engage, Reorient Experimental Satellites (SPHERES) flat floor facility, using a 2 m × 2 m portion of floor space for the SPHERES to traverse. The SPHERES satellites (**Fig. 1A**) contain propulsion, navigation, avionics, power, and communication subsystems[12,27] and can be controlled in 3 degrees of freedom (2 translational and 1 rotational axes). The state of the satellites was determined using five ultrasonic beacons that send signals to ultrasound receivers on each face of the satellite. Attitude and angular rate are determined with an onboard inertial measurement unit.

Two SPHERES were used for this study, with the motion of the SPHERES defined as a simplified and sped-up version of satellite motion in orbit projected onto a two-dimensional view.[24] The use of hardware was selected to increase the simulation fidelity, as previous driving studies have shown that simulation fidelity can affect human performance.[11,33] The two SPHERES under manual control were modeled to have slightly different inclinations in orbit, which maps to an off-set oscillation within the 2D view. The subjects could change the position of the SPHERES in the 2D view by initiating a parallel or perpendicular burn (thruster activation) during the orbits. Manual control was implemented using keyboard inputs (**Fig. 1B**). A parallel burn created translation in the y-axis and

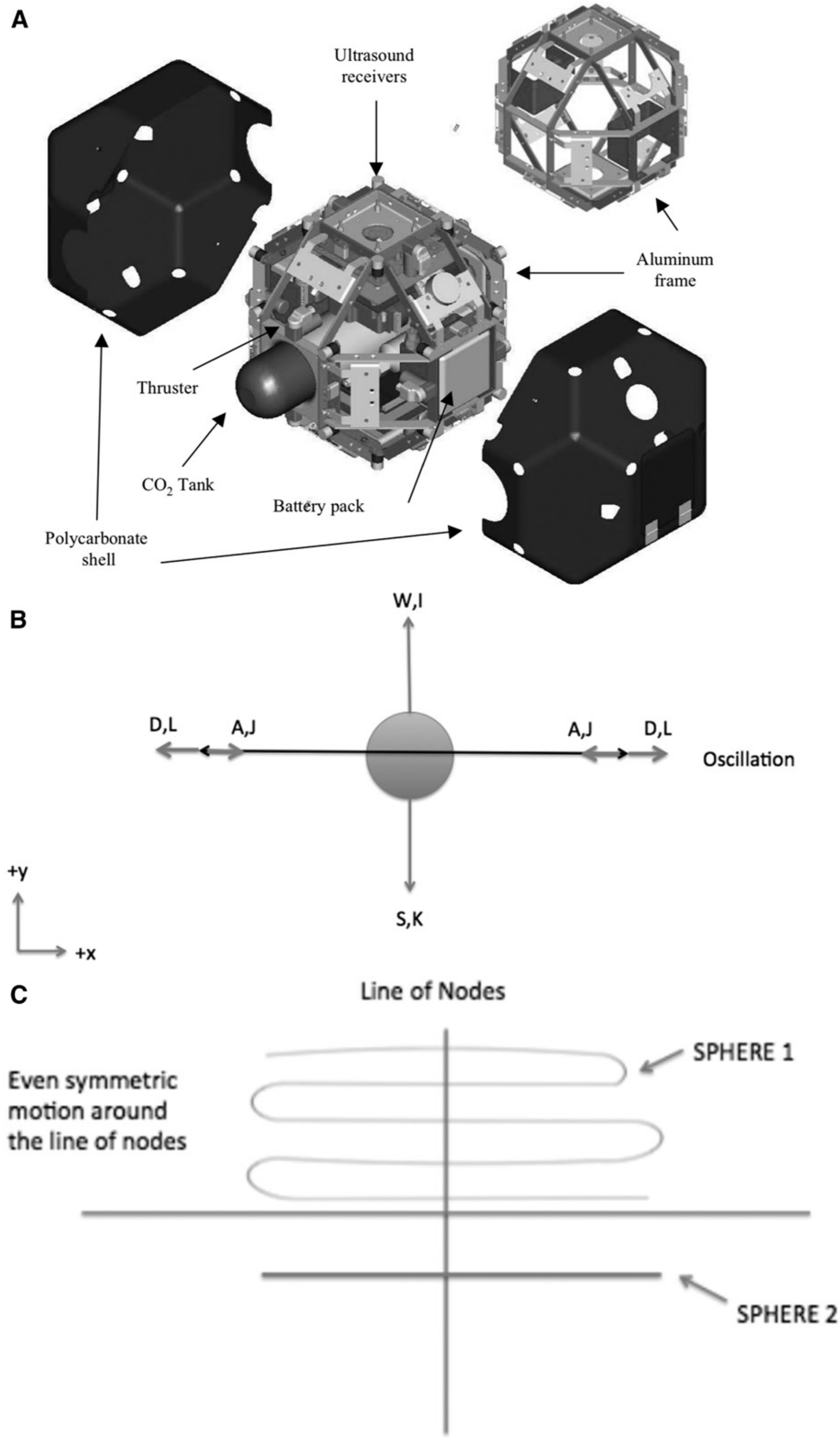

Fig. 1. A) 3D model of the SPHERES satellite.[12] B) The SPHERES are controlled using keyboard presses mapped as follows: 'w' and 'i' controlled motion in the positive y-axis, 's' and 'k' controlled motion in the negative y-axis direction, 'd' and 'l' increased x-axis oscillation amplitude, and 'a' and 'j' decreased x-axis oscillation amplitude. C) Sample trajectories of the SPHERES with SPHERE 2 oscillating along the horizontal line shown. A parallel burn creating positive y-axis motion creates the SPHERE 1 trajectory with a combined left-right oscillation and positive y-axis motion.

a perpendicular burn changed the magnitude of the oscillation amplitude along the x-axis (**Fig. 1C**). While keys could be pressed at any time, subjects were told the control input would only be implemented as the SPHERES crossed the x-axis midpoint of the space, which corresponded to the line of nodes. In orbital mechanics, this is the point in the orbit when a controlled thrust should be made to change a satellite's inclination with an optimized amount of fuel. Data from the SPHERES were transferred to a computer and imported into Matlab (Mathworks, Natick, MA) using a custom plugin for later analyses.

Visual feedback was provided to the subjects using either a Basic display or Augmented display (**Fig. 2**). Both displays provided information on the location of the SPHERES and debris, the operational boundary, and the reaction task. The basic interface design was a minimal set of information designed to emulate what could be seen on the actual testbed environment. The display showed the two satellites, with a shadow for the size of their air carriages, and the 2 × 2 m operational boundary. A red light reaction task was placed on the right side of the display on both interfaces. This display was gray when there was no action required and red when response was required. A response was provided by pressing 'c' on the keyboard. The augmented interface design used the basic design with additional SA aids. It provided location of the line of nodes (where the control action would be engaged), the SPHERES' oscillation magnitude, the projection of SPHERES future location, and a proximity warning. A proximity warning (indicated by a red circle) was activated if the satellite was too close to the other satellite or space debris. The dotted line down the center of the screen represented the line of nodes. Projection shadows of the future location of the satellites were shown as blue, light blue, and white boxes to represent 3, 6, and 9 s in the future, respectively. The two blue boxes on each side of the SPHERES were oscillation magnitude markers, which designated the maximum point of oscillation of each SPHERES center of mass based on the current state.

Procedure

Training occurred on the first day of a 9-d randomized order cross-over protocol. Nights 1–3 were Condition 1 (detailed

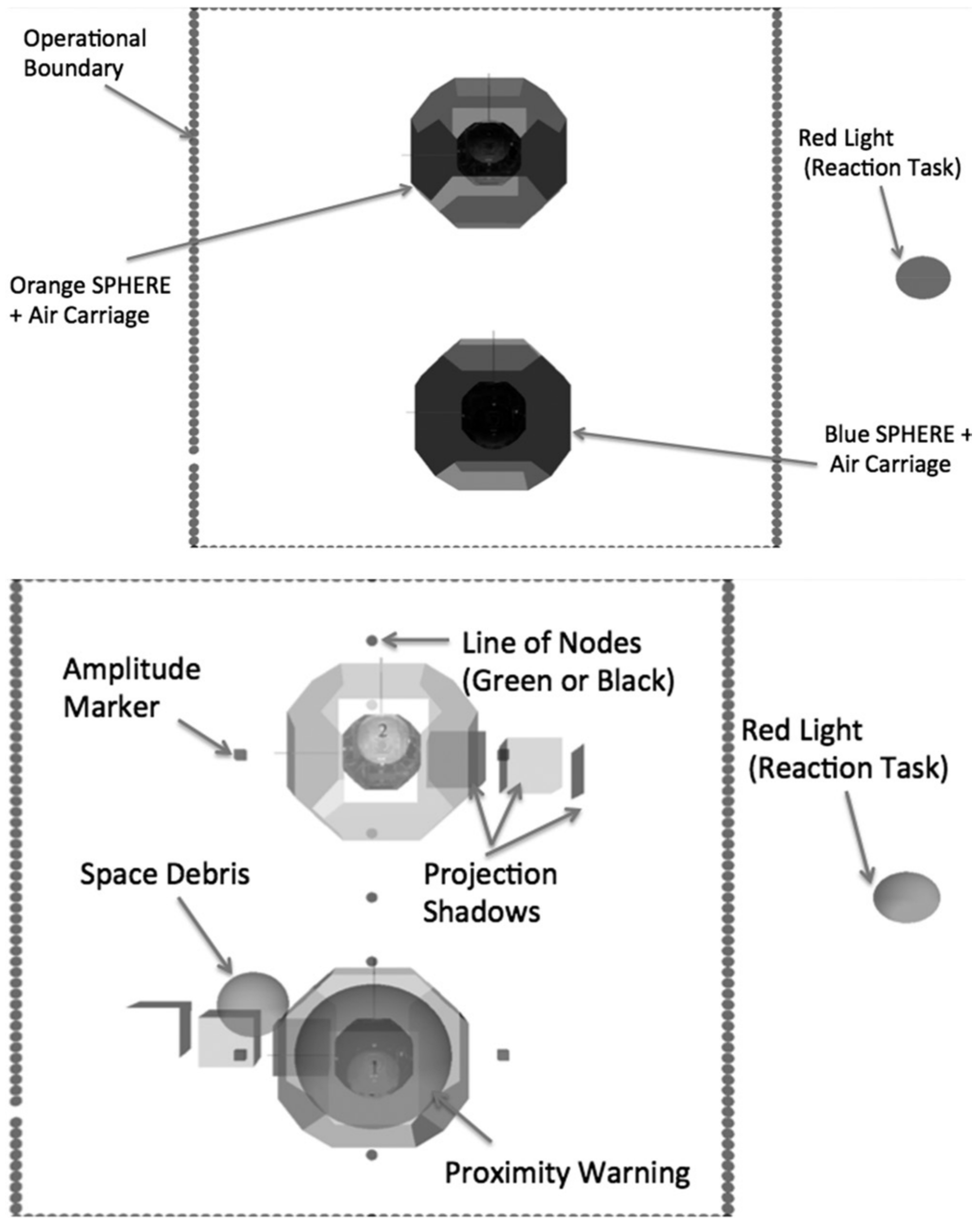

Fig. 2. Basic display (top) and augmented display (bottom). Displays were shown in color.

below), testing session 1 was on day 4, nights 4–5 had a minimum of 6 h of sleep, nights 6–8 had Condition 2, and testing session 2 was on day 9. The two Conditions were rested or "sufficient sleep" (SS, 9 h of time in bed per night, with a minimum of 7 h of actual sleep) and sleep restricted (SR, 3.5–4.5 h of time in bed). Sleep and wake times were monitored throughout the 9-d study using wrist actigraphy and a sleep log that included hours of sleep, sleep quality, and sleepiness after waking.

Subjects were allowed to examine the hardware prior to the test. Then they were seated at a desk with a visual barrier such that they were unable to see the SPHERES maneuvering during operations, but were able to hear them during the test. Subjects were aware that they were controlling actual hardware.

During the training day, a background questionnaire that included questions on video game experience, weekly sleeping habits, and morningness/eveningness preference was completed and subjects were given a training guide on the interface and task scenario with unlimited time to understand the material. A research team member was present to answer questions about the study. Completion of this part of the training was assessed with knowledge-based questions to ensure that the subjects could operate the SPHERES satellites. Once subjects answered all questions correctly, they proceeded with hands-on training.

Subjects viewed the 2D representation of the SPHERES motion and simulated space debris on a computer monitor (Fig. 2). Space debris was configured to start at the edge of the operational area and linearly traverse the area over a 120-s trial. There were six different debris start locations used (i.e., the corners of the operational area and the top and bottom of the line of nodes), with each location used once for each treatment (i.e., Condition × Augmentation combination). Different start locations were chosen so subjects would learn a strategy to control the SPHERES in the general presence of debris and not specifically learn the pattern of key presses for a single location. A secondary task required subjects to respond to a red light (i.e., by pressing 'c' on the keyboard) that activated at four preset times (based on the trial) during the 120 s. The "light on" times were paired with one of the debris configurations. The task scenario required that subjects control both SPHERES simultaneously (using the keyboard) in order to avoid collisions between SPHERES or with debris, or avoid leaving the boundary. The participant could not control motion of the debris. Feedback on SPHERES and debris location was provided to the user through the visual display (Augmented or Basic). The nominal oscillations of the SPHERES in the starting configuration would not induce a collision between the SPHERES. However, all debris scenarios required control input to avoid collision. During the task, subjects were instructed to have the following priority:

1. Ability to have SPHERES not collide with each other, the space debris, or the operational boundary (a 2 m × 2 m space) within the 120-s trial.
2. Ability to conserve fuel by limiting the number of times they sent a control input.
3. Ability to react to the secondary task (i.e., respond to the red light).
4. Ability to accurately complete the posttrial questionnaire at the end of each trial.

Subjects interacted with both Augmented and Basic display conditions. A subset of tasks was completed to ensure understanding of the control implementation. Debris avoidance strategy was not discussed during the training day. Hands-on training was complete once a participant had successfully completed all tasks. Then, subjects were introduced to the SA questions to be answered after each trial, and were given an actigraph and sleep log. The SA questions included notation of the starting and ending position and direction of motion of each of the SPHERES, relative position between the SPHERES and the debris at the start and end of the trial, and perceived usage of the fuel (number of control key presses).

The two test sessions were scheduled at least 4 h after the participant woke up to avoid sleep inertia effects.[5] When the subjects arrived for a test session, their sleep logs were reviewed and the sleep/wake times later validated by the actigraph results. Actigraph data were not examined for sleep efficiency. Next, subjects repeated the training protocol to confirm the ability to nominally control the SPHERES. This portion of training was not timed. Subjects then performed 12 debris-avoidance trials, with a break after 6 trials. The presentation interface type was randomized across the 12 trials.

If there was a collision during the trial or the SPHERES crossed the operational boundary, the trial was terminated. Subjects were given the Epworth Sleepiness Scale (ESS)[15] prior to trial 1, after trial 6, and after the last trial. A Visual Analog Scale (VAS)[17] for sleepiness was administered prior to trial 1 and after trials 3, 6, 9, and 12. The SA questionnaire was administered at the end of each trial. If the subjects fell asleep during the trial, the test administrator immediately woke them up and continued the trial.

Statistical Analysis

Data were recorded by a laptop communicating with the SPHERES during every control input cycle (1 Hz). These data were postprocessed using a custom Matlab program. The raw data transferred from the SPHERES included the trial survival time, number of burns executed, and the location and orientation of the SPHERES and debris. The survival time ranged between 0–120 s, as 120 s was the maximum time allowed in the simulation. Area covered was defined as the sum of the two individual SPHERES cover areas estimated using the maximum and minimum x and y positions attained. The data from the SA questionnaires included the number of perceived burns, perceived ending satellite and debris positions, and participant projections of satellite and debris motion.

Motion perception ("Average Directions Correct") was defined from the SA questionnaire and state data to compare the actual ending motions of the satellites with the perceived motions from the SA questionnaire across the trials. A value of 1 was given for each SPHERES for which the motion of the satellite was correctly determined to be in the recorded quadrant (including boundaries of the quadrant). Since there were two SPHERES, Average Directions Correct for each trial could take on the value 0, 1, or 2.

Data from the Morningness/Eveningness questionnaire[29] has a range of 16–86, with a higher score corresponding to more "morning" activities preference. For the subjective sleepiness scales (i.e., ESS and VAS), a higher score meant the participant felt more tired, with a maximum score of 24 for the ESS and of 10 for the VAS.

The dependent measures considered here were survival time, area covered, Average Directions Correct, ESS, and VAS. There were two primary factors (Augmentation and Condition) each with two levels, leading to four treatments. An effect of Order and Test Session were also considered when appropriate. The effect of SS vs. SR Conditions on the ESS and VAS was assessed using a paired *t*-test. Survival time and area covered were assessed using an ANOVA model; survival time was inverse transformed and the area covered was log transformed before entry into the model to meet model assumptions of normality and constant variance. The ANOVA models included Subject (random factor nested within order), Test Session (first vs. second session), Order (SS vs. SR first), Condition (SS vs. SR), Augmentation (Basic vs. Augmented display), and their interactions. If interaction effects were found, Tukey post hoc pairwise comparisons were performed. The untransformed values are also presented. A Chi-squared test was performed to analyze motion perception.

RESULTS

Subjects reported sleeping an average of 7.52 h per night (range of 6.71–8.54, SD = 0.6 h) before the 9-d protocol began from the background questionnaire. Only two subjects had consistent experience with video games. The Morningness/Eveningness Questionnaire score data indicated that six of the eight subjects had "intermediate" habits, one was "moderate evening," and one was "moderate morning." All subjects successfully completed the initial training and test-day training review, signifying an ability to control the SPHERES.

Of the eight subjects, seven completed the protocol in 9 d and one participant completed the protocol in 10 d after misunderstanding instructions and taking an extra day in between the SR and the SS condition. There were two subjects who overslept 1–2 h on a SR night that was not the night immediately preceding the test session.

A total of 184 trials were completed and analyzed. Due to telemetry transmission failure, three trials were not analyzed. Because one participant had to leave early for nonstudy reasons, five trials were not completed. Of the 176 completed trials, only 12 trials (6.5%) ended without a collision. For perceived sleepiness, there was an effect of Condition with subjects feeling more fatigued during the SR than the SS Condition on both ESS and VAS (**Fig. 3**).

For the inverse of survival time (**Fig. 4A**), there was an effect of Order [$F(1,152) = 6.24$, $P = 0.046$] and an trend of Condition and Order [$F(1,152) = 4.63$, $P = 0.074$], but no significant effect of Augmentation or interaction of Condition or Order with Augmentation. Post hoc tests found there was no difference between Orders for the First Session (95% CI = −0.005, 0.006 s^{-1}, $P = 0.994$). There was a decrease in the inverse survival time (i.e., better performance) for the Second Session compared to the First Session if the Order was SS-SR (95% CI = −0.001, −0.013 s^{-1}, $P = 0.018$). No effect of Test Session was found for the Order SR-SS (95% CI = −0.008, 0.004 s^{-1},

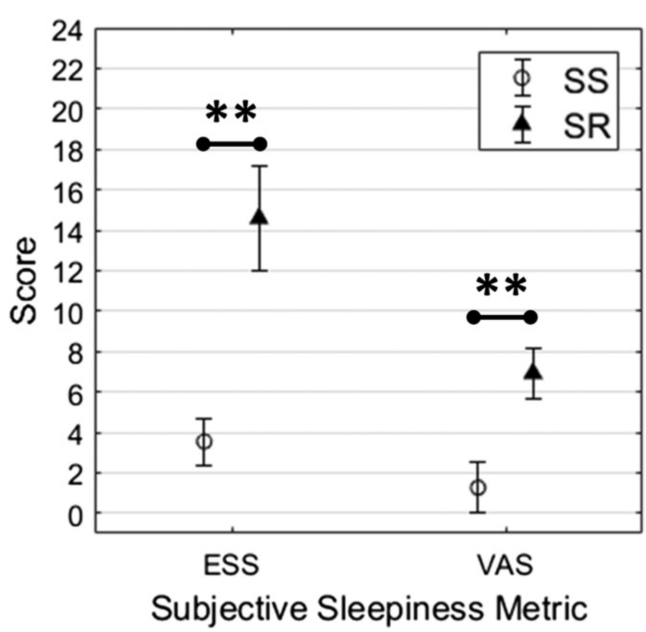

Fig. 3. Effects of condition (SS or SR) on subjective sleepiness using Epworth Sleepiness Scale (ESS) or Visual Analog Scale (VAS) metrics. **Indicates $P < 0.0005$.

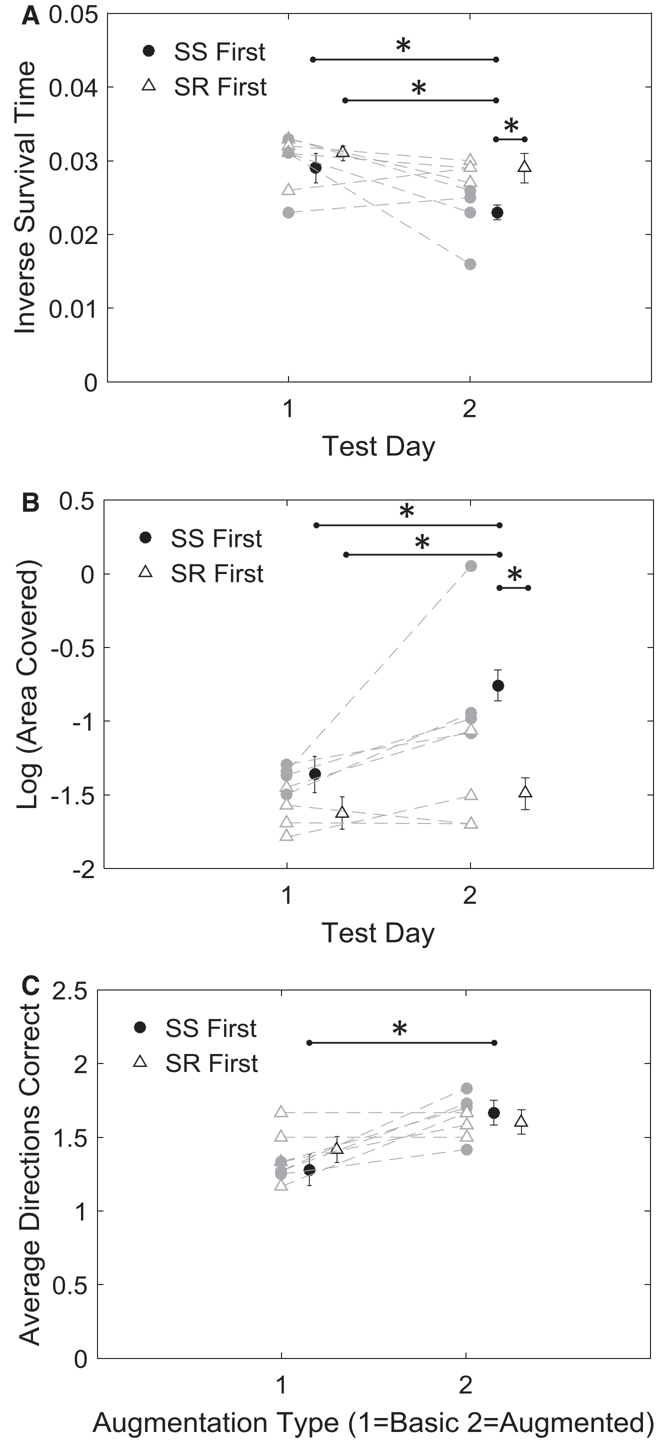

Fig. 4. A) Test session vs. inverse of survival time (lower = better). B) Test session vs. log of area covered (higher = more area covered). C) Augmentation vs. average directions correct (out of 2). Individual mean (gray) and treatment mean ± SE (black) values are plotted, with mean values plotted slightly to the right of individual values for ease of viewing. Black circles are for Order SS-SR; white triangles are for Order SR-SS. *Indicates $P < 0.05$.

$P = 0.829$). Better performance was observed for the Second Session with Order SS-SR compared to Order SR-SS (95% CI = -0.014, $-0.002\ s^{-1}$, $P = 0.002$). When considering the untransformed survival times, the estimated mean was 55.9 s and the median was 44.0 s for Order SS-SR for the Second Session. The estimated mean was 42.7 s and the median was 33.5 s for Order SR-SS for the Second Session.

For natural log of area covered (**Fig. 4B**), there was an effect of Order [$F(1,152) = 11.359$, $P = 0.028$] and an interaction effect of Order and Condition [$F(1,152) = 6.74$, $P = 0.039$] (Fig. 4), but no significant effect of Augmentation or interaction with Augmentation. Subjects who were in the SS-SR Order for the Second Session covered a larger area than any other combination of Session and Condition. There was no difference between Orders for the First Session [95% CI = -0.283, 0.542 $\ln(m^2)$, $P = 0.851$]. There was an increase in the natural log of the area covered for the Second Session compared to the First Session if the Order were SS-SR [95% CI = 0.191, 1.019 $\ln(m^2)$, $P = 0.001$]. No effect of Test Session was found for the Order SR-SS [95% CI = -0.264, 0.527 $\ln(m^2)$, $P = 0.829$]. An increase in the natural log of area covered was observed for the Second Session with Order SS-SR compared to Order SR-SS [95% CI = 0.468, 1.264 $\ln(m^2)$, $P < 0.0001$]. When considering the untransformed area covered, the estimated mean was 0.606 m^2 and median was 0.479 m^2 for Order SS-SR for the Second Session. The estimated mean was 0.289 m^2 and the median was 0.244 m^2 for Order SR-SS for the Second Session. For Average Directions Correct (**Fig. 4C**), with both Sessions pooled, subjects that were SS on the first session did receive benefit from the Augmentation [$\chi^2(2) = 8.012$, $P = 0.018$] while those that were SR on the first session did not [$\chi^2(2) = 2.710$, $P = 0.258$].

DISCUSSION

In this pilot study, the best performance using survival time, area covered, and motion perception metrics occurred in the SS-SR Order on the SR day; the main effects of Condition or Augmentation were not significant. The 6.5% success rate across trials suggests that the task was very complex for these novice system users. The training did not include practice with debris avoidance and thus changes in participant strategy were observed across trials as measured by area covered. Covering a larger area burned more fuel, so the subjects had to prioritize survival over fuel conservation effectively even though they were told to save fuel. Since the Augmentation was randomized, carryover from one interface to the other may have occurred and may be a reason the data did not support a main effect of Augmentation. Similarly, the ability to carry over knowledge from the first to second session may be a reason the data did not support a main effect of sleep Condition.

While these results may initially appear to contradict other findings of detrimental effects of sleep loss on performance,[3,31] they can be interpreted in the context of how sleep loss affects the ability of a participant to learn a complex task. Learning depends on sleep.[28,32] In the context of the current study design, this suggests that if the first session is considered a training day, then sufficient sleep is required for that training to carry forward to another session. This was seen in our data: subjects in the SS-SR Order did better (i.e., longer survival time) on the SR day than those in the SR-SS Order on the SS day, even though those in the former had less sleep immediately before the test day. This finding has important implications on the effect of sleep loss for learning a complex task.

Subjects that were in the SS-SR Order covered more area on the second day and subjects with the longest survival time tended to have a greater area covered. Increasing area covered is a more aggressive strategy for debris avoidance and negatively impacted fuel efficiency. Therefore, subjects appropriately followed the priorities provided of maximizing survival time at the expense of fuel consumption. These data support that learning in a well-rested state may support development of appropriate strategies for better performance.

Subjects were also better able to use the Augmentation display if the Order was SS-SR. Subjects that were SS during the first session were better able to use the augmentation and may have developed a better mental model of the task and the system. Subjects may have understood the state of the system (Level 1 SA) and the short-term projections (Level 3 SA) of the system from the augmentation without fully comprehending (Level 2 SA) the system and using this comprehension to generate long-term projections (Level 3 SA) of how the system would change going forward. While Average Directions Correct provided an understanding of perception (Level 1 SA), we did not specifically analyze a participant's ability to project state information forward in time. Subjects may have had a poor mental model of the strategy required to obtain specific altered trajectories even though they understood the underlying input controls. Since subjects were able to use the augmentation better if in the SS Condition during the first session, this may have aided in development of the mental model of the task. An improved mental model when beginning with SS in the first session would be expected to improve performance while SR during the second session. These results support Endsley's[10] comments that sleep enables optimal integration of situation cues and mental model to enable performance.

For this initial pilot study, some allowances were given for failure to strictly follow the sleep schedule portion of the protocol. The inclusion of these subjects may have added variability to the measures of interest, but were deemed to not invalidate the protocol. However, this variability would naturally occur in an operational environment. The complex nature of this debris avoidance task enabled observation of interesting interaction effects between Order and Condition. While a simpler task may have permitted a classic main effect of SR to be observed, operational tasks in the natural environment may not be as simple. This study extends the literature by specifically examining a task that required perception, comprehension, and projection to select the appropriate motor action response. Here we were unable to disambiguate the effects of learning strategy in the context of Augmentation.

Future studies should consider evaluating the development of strategy by blocking for Augmentation rather than randomizing within the Order × Condition treatment. Future research should also consider including four different Condition levels to better understand how Condition affects learning: SS both test days, SR both test days, SR-SS, and SS-SR. Using hardware created a more realistic psychological state in the participant while sacrificing ease of experimental execution. To gather a larger dataset, simulations may be preferred over hardware. This study needs to be replicated with a larger number of subjects. Inclusion of additional subjects would permit a formal evaluation of previous video game usage. For other work, even when SR is not the primary intent of a study, researchers should consider as a covariate or control the sleep history (e.g., sleep duration over many days) of study subjects, especially in longitudinal studies as sleep duration before and after a training period may be a significant factor in the results.

The results of this study are relevant to satellite operations, control of multiple robotic assets, and generally complex tasks. The results suggest that learning of a complex task requiring perception, comprehension, and projection of multiasset control and of information displays is better after receiving sufficient sleep (compared to restricted sleep) for multiple days. Since future operations of technical organizations will include varying levels of automation and human control of multiple assets, these organizations should understand what role an operator's sleep history may play in learning and performance. This understanding should be twofold: organizations should understand the effects of sleep loss separately on learning and on performance. Since sleep restriction is widely considered acceptable in today's culture and is a problem of increasing magnitude, a large portion of a workforce may not have experienced sufficient sleep prior to going to work. During training of employees, these organizations should ensure that each person receiving training is well rested. Policies should also be established that discourage working while under SR conditions and make sure that incentives do not generate emergent influences that would reward working under sleep loss (either SR or sleep deprivation). Based on the results of this study, being well rested during training periods may mitigate some negative aspects during day-to-day operations. Organizations should consider these data when preparing operators of multiple robotic assets for difficult and complex tasks.

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