Research Article

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Investigating the psychological and physiological responses to isolation and confinement using the THOR space analog simulation

Investigando las respuestas psicológicas y fisiológicas al aislamiento y confinamiento utilizando la simulación análoga espacial THOR

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Resumen

This research investigates astronaut performance under simulated space conditions, using THOR, an analog astronaut training protocol, during a week-long confinement in an Analog Astronaut Training Center in Poland. Materials and Five participants, including four military and one civilian, underwent a week of isolation. Tests were conducted to assess heart rate variability –HRV–, psychological health, and sleep patterns. Data collection and analysis were standardized, with an alpha level of $p < 0.05$ and power of 80%. The study found reductions in fat percentage and weight, while muscle mass and water content remained stable. HRV showed significant changes. Increased sleep and state anxiety levels were noted, along with decreased cognitive abilities. Personality traits exhibited heightened hostility and social anxiety, culminating in psychological discomfort. HRV values were normal with variations likely due to stress. A significant correlation was found between mental performance and HRV, indicating potential influence of sleep on cognitive function during isolation. The study highlights the need for more research on the psychological and physiological implications of long-duration space missions and similar high-demand environments.

Keywords: Analog Astronaut performance; THOR simulation; spaceflight conditions; isolation; confinement; heart rate variability; HRV; psychological health; sleep patterns; cognitive abilities; autonomic response; short-duration space missions; spaceflight physiology; neuropsychology; cognition; high-demand environments

Abstract

Esta investigación examina el rendimiento de los astronautas análogos bajo condiciones espaciales simuladas durante una semana de confinamiento en un Centro de Entrenamiento de Astronautas Análogos en Polonia. Cinco participantes, incluyendo cuatro militares y un civil, fueron sometidos a una semana de aislamiento. Se realizaron pruebas para evaluar la variabilidad de la frecuencia cardíaca –HRV–, la salud psicológica y los patrones de sueño. La recolección y análisis de datos fueron estandarizados, con un nivel alfa de $p < 0.05$ y una potencia del 80%. El estudio encontró reducciones en el porcentaje de grasa y peso, mientras que la masa muscular y el contenido de agua permanecieron estables. La HRV mostró cambios significativos. Se observaron niveles elevados de sueño y ansiedad estado, junto con disminuciones en las habilidades cognitivas. Los rasgos de personalidad mostraron una hostilidad y ansiedad social aumentada, culminando en incomodidad psicológica. Los valores de HRV fueron normales con variaciones probablemente debidas al estrés. Se encontró una correlación significativa entre el rendimiento mental y la HRV, indicando la posible influencia del sueño en la función cognitiva durante el aislamiento. El estudio resalta la necesidad de más investigaciones sobre las implicaciones psicológicas y fisiológicas de las misiones espaciales de larga duración y entornos similares de alta demanda.

Palabras clave: Rendimiento de astronautas análogos; simulación THOR; condiciones espaciales; aislamiento; confinamiento; variabilidad de la frecuencia cardíaca; HRV; salud psicológica; patrones de sueño; habilidades cognitivas; respuesta al estrés; misiones espaciales de corta duración; fisiología del vuelo espacial; neuropsicología; cognición; entornos de alta demanda

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Introduction

Human space exploration necessitates precise astronaut selection and training for optimal performance and safety in extreme, distant environments (Steimle & Norberg, 2013). Commercial astronaut training, using analog environments for high-fidelity spaceflight simulation, has risen in scientific prominence, offering unique opportunities to study human performance during brief space missions (Ilaria, 2020). These environments challenge astronaut behavior, (Roma et al., 2021), physiology (Hughson et al., 2012), and cognition (Desai et al., 2022), due to altered gravity, ionizing radiation, high workload, disrupted circadian rhythm, and limited immediate support, while necessitating high cognitive and physical performance for a rigorous schedule of scientific experiments (Bartone et al., 2019). Reported neurobehavioral challenges during spaceflight, such as altered time perception (Yusupova et al., 2022), concentration and memory deficits (Salazar et al. 2022), attention lapses and reaction delays, can impede efficiency and impact mission execution. Current cognitive and behavioral tests, however, lack sensitivity for detecting subtle performance decrements in high-performing astronauts, particularly during deep-space exploration missions (Strangman et al., 2014). This study evaluated cognitive performance, heart rate variability, and emotion in crewmembers of the THOR space simulation, during a 7-day confinement at the ground-based Analog Astronaut Training Center –AATC– in Poland, where analog astronauts conducted scientific experiments spanning biology, engineering, physiology, computer science, and psychology

Material and Methods

The Lunar base simulator, a habitat emulating a lunar environment for analog missions, houses a five-member crew isolated from fresh air and natural light. Comprising laboratory, hygiene, shelter, dormitory, gym, and galley sections, it serves as a platform for diverse experiments including human factors, engineering, psychiatry, biology, and neurobehavioral aspects of spaceflight. Over 50 missions have been executed since its establishment in Rzepiennik, Poland. Communication is facilitated via internet service providers like Starlink.

THOR Campaign

The space simulation exercise engaged four military cohorts along with a civilian participant, originating from a range of disciplines including, but not limited to, aviation, engineering, biology, chemistry, and aerospace medicine. The selection procedure for this simulation was executed under the auspices of the COLAF Direction of Aerospace Medicine. Initial applications were solicited in relation to research projects destined to be executed within the simulated habitat. These applications underwent rigorous scrutiny by the Aerospace Medicine and Neuroscience Group, a division of the Aerospace Science Sub Directorate. Subsequent to this initial assessment, shortlisted candidates were subjected to interviews and evaluations conducted by professional psychologists. A comprehensive medical examination was also implemented to ensure the candidates' psychophysical aptitude for the mission. In August 2022, a week-long exercise of isolation and confinement was preceded by a month of baseline data collection and training. Emulating the International Space Station –ISS–, the mission incorporated 15 research tasks, repair work, emergency drills, and stress induction, managed by the 24/7 supervising Mission Control Center –MCC–. The MCC, with its around-the-clock surveillance through cameras, microphones, and environmental sensors, governed a predefined schedule encompassing 14 hours of work, 8 hours of sleep, with residual hours assigned for meals, leisure, and other mission-related tasks. The five-member crew held roles as Crew Mission Commander –CMC–, Crew Data Officer –CDO–, Crew Space Engineer –CSE–, Biomedical Engineer –BME– and Crew Medical Officer –CMO–, while the MCC team comprised of a Flight Director –FD–, Capsule Communicator –CapCom–, and Remote Support Officer –RSO–. Pre-mission training involved trust-building, leadership, and psychophysiological performance exercises, focusing on endurance, behavioral responses, and ambiguous information problem-solving. Cold stress tolerance was measured in a -120°C cryochamber for three minutes as part of the training, and team dynamics were evaluated during a cold-water swimming and a 10-minute float test.

Habitat

The habitat, a space simulation facility, features an environmental control system for stable temperature and humidity, recycled air inlets, temperature-adjusted clean lab and restroom, along with heaters for the galley and dormitory. The Crew Medical Officer –CMO– assembled environmental sensors (BME680, GM-102B to GM-702B, SCD-41) as part of an experiment, enabling crew to monitor factors like barometric pressure, temperature, relative humidity, carbon monoxide, carbon dioxide, and volatile organic compounds, with data showcased on a thin-film transistor liquid-crystal display. The study investigated psychophysiological shifts during a week-long isolation, examining heart rate variability, cognition, emotion, vigilance, sleep, and anthropometrics.

Subjects

Five crew members were selected by the Direction of Aerospace Medicine, passing an extensive screening that included physical examination by an aerospace medicine specialist, psychological interview, anthropometric measures, indirect VO2, electrocardiogram, blood chemistry, hemogram, and urinalysis. Chosen subjects had appropriate education, technical skills and/or military experience akin to real astronauts and consented to participation after full disclosure. Ethical approval was granted by the Postgraduate Air Force School and all participants gave their informed consent. The five participants (ages 26-42, mean 31, SD ± 6.8) comprised four males and one female, with BMI 22-27 Kg/m^2 (24.5 ± 1.9), Fat% 17-33 (median 19.2 ± 6.6), muscle 37-61 (median 59 ± 9.9), indirect VO2 35-69 mL/kg/min (51.6 ± 12), unremarkable medical history, no substance use, and normal vital signs. Blood samples were taken at the Direction of Aerospace Medicine Laboratory for pre- and post-mission assessments. The participants' education was split between 80% Bachelor's degree and 20% Master's degree holders.

Heart Rate Variability

HRV and indirect VO2 were estimated from RR intervals using Polar V800 with H7 band during 1-hour rest periods at baseline (BL), and on mission days 1 (MD-1), 3 (MD-3), and 5 (MD-5), following established procedures (Caminal et al., 2018). Data, saved on 8 MB internal memory, was downloaded as a .txt file from polarflow.com, associated with each device, and analyzed with Kubios (Tarvainen et al., 2014) software for time, frequency domain, and non-linear aspects of HRV for each space analog crewmember.

Neuropsychological tests

Space Analog crewmembers completed the validated versions for Spanish-speaking population of the Brief Symptom Check List (LSB-50), Stress Assessment Scale (EAE-G), State-Trait Anxiety Inventory –STAI–, and State-Trait Depression Inventory –IDER– on Mission Day-1 (MD-1) and MD-6 to screen for psychological, psychosomatic symptoms, perceived stress, and euthymia-dysthymia changes. On MD-5, the CMO, trained by the Direction of Aerospace Medicine neuropsychology service, administered NEO PI-R, Symbol Digit Modalities Test (SMDT), Rey-Osterrieth Complex Figure Test (ROCF), and Wechsler (WAIS-IV) to assess personality traits, memory, processing speed, attention, visual memory, executive function, and perceptive reasoning. Reaction time (rT) was measured daily with NASA-PVT+ on an iPadOS one-hour post-wake, from baseline, throughout the four jetlag days, and from MD1 to MD6. Data was stored internally and downloaded as a .csv file 1-2 hours post-wake as per the mission schedule in Figure 1.

Figure 1. *Mission Schedule for THOR Space Analog Simulation.*

		Mission Time (h)									
		0	1-2	3-4	4-5	6-7	8-9	10-11	12-13	14-15	16-24
Mission day	MD_1	Wake up	HRV, PVT, KSS, SP, PANAS	Break + B	R&M, E	Lu	LSB-50, EAE, STAI, IDER	R&M, E	Exp + E	Din/Debriefing/Log	Sleep
	MD_2		Exp + E + PVT	Break + B	Exp + E	Lu	Exp + E	Exp + E	Exp + E		
	MD_3		Emergency 1		Emergency 2		NASA-TLX, HRV, PVT, KSS, SP, PANAS	Exp + E	Exp + E		
	MD_4		Exp + E + PVT	Break + B	Exp + E	Lu	Exp + E	Exp + E	Exp + E		
	MD_5		HRV, PVT, KSS, SP, PANAS	Break + B	Exp + E	Lu	SDMT, Rey Fig - NEO PI-R, Wechsler				
	MD_6		Exp + E + PVT	Break + B	Exp + E	Lu	LSB-50, EAE, STAI, IDER	Exp + E	Exp + E		
	MD_7		Exp + E	Break + B	Cleaning Mission End		Mission Debriefing				

R&M: Repairs and maintenance. E: Physical activity. Exp: Experiments.
B: Briefing. Break: Breakfast. Lu: Lunch. Di: Dinner. HRV: Heart rate variability.
PVT: Psychomotor Vigilance test. KSS: Karolinska Sleepiness Scale. SP: Samn-Perelli Fatigue Rating.
PANAS: Positive affect and Negative affect. NASA-TLX: Task Load Index.

Positive affect and Negative Affect (PANAS)

Using the Spanish PANAS scale, analog astronauts reported daily positive and negative affect, scoring ten components each from one to five. Responses were collected via the TapForms app on iPad, and downloaded as a csv. To ensure security and privacy, digital files were encrypted with a unique ID, with access limited to the CMO.

Sleep

Prior to isolation, the CMO screened crewmembers for sleep disorders and hypersomnia using Spanish versions of the Pittsburgh Sleep Quality Scale (PSQS), Epworth Sleepiness Scale –ESS–, Samn-Perelli –SP– scale, and Karolinska Sleepiness Scale –KSS–. During the mission, morning surveys, administered on iPad, gathered data on sleep quantity and quality through KSS and SP scale, cross-referenced with Polar V800 wrist-worn actigraphy. Post-emergencies, NASA-TLX was utilized via iOS to gauge perceived workload.

Statistical Analysis

Statistical analysis, performed with MedCalc (v20.104), implemented normality tests such as Kolmogorov-Smirnov and Shapiro-Wilk alongside Q-Q plots. Based on results, appropriate parametric and non-parametric statistics were applied. Paired sample t-tests, ANOVA, and linear regressions were used for relevant comparisons and correlations. Significance level was set at $p < 0.05$ and power at 80%.

Results

Environmental parameters in the habitat varied across the mission days. Significant differences were found in temperature and relative humidity ($Chi^2 = 450$, DF 2, $p < 0.0001$) with humidity peaking at the end. Median CO^2 was initially 488 ppm but measures such as ventilation optimization and cooking off-gas reduction decreased CO^2 levels significantly ($F(1, 2) = 50401$, $p < 0.00001$). A similar trend was observed for CO and VOCs. Variances in these parameters were notable on MD-1, MD-3, and MD-5.

Pre- and post-mission evaluations revealed significant changes from the baseline. A 3.08 ± 1.8% decrease in fat percentage was found ($t(4) = 3.7$, $p = 0.020$), contributing to an average weight loss of 0.38 kg, unlinked to muscle mass, water content, or bone mass changes. This may have been influenced by increased daily exercise, raising caloric burn from 1800 to 2520. Hemoglobin levels fell by 0.5 mg/dL ($t(4) = –2.795$, $p = 0.0491$) potentially due to higher barometric pressure exposure, and fasting glucose dropped by 4.4±2.4 mg/dL ($t(4) = –4.080$, $p = 0.0151$), possibly related to weight loss. No significant alterations were noted in kidney function, lipid profile, uric acid, or urinalysis

Time-domain results

During the six-day isolation and confinement exercise, we compared time domain HRV measures to the baseline. Mean R-R didn't significantly differ overall (F (1.534, 4.36), p = 0.072). However, a negative trend was found comparing Mean RR from baseline to MD-3, when two emergencies occurred, with a mean difference of 149 ms (IC95% 32 – 266, p = 0.024). Mean Heart Rate –MeanHR– showed significant variation (F(1.507, 5.72), p = 0.046, Table 1) but no statistically significant pairwise differences. MeanHR elevation on MD-3, possibly due to emergencies and time pressure, had a within-subjects variation of 11.25%, averaging 73.4 ± 8.25 bpm.

Table 1. *Time-domain results of the heart rate variability among baseline, mission day 1 (MD-1), mission day 3 (MD-3) and mission day 5 (MD-5).*

Variable	Baseline	MD-1	MD-3	MD-5	F	p
MeanRR (ms) (CI95%)	860 (706–1014)	786 (645–926)	710 (641–780)	801 (675–928)	4.36	0.072
MeanHR (bpm)	70.8 (59–83)	77.5 (65–91)	84.8 (76–94)	76 (64–88)	5.72	0.046
SDNN Index (ms)	92.6 (78–108)	92.8 (78–107)	70.2 (59–82)	112 (83–141)	3.30	0.125
pNN50 (%)	28.7 (15.59–41.8)	16.9 (3.6–30.2)	10.55 (4.03–17.06)	21.2 (5.20–37.19)	5.18	0.031
RMSSD (ms)	103.6	68	35.2	118.2	3.002	0.135
RR Triangular index (ms)	16.9 (11.7–22.2)	14.6 (10.9–18.3)	11.3 (8.9–13.8)	15.2 (11.3–19.0)	5.55	0.027
TINN (ms)	1925.4 (–620.1 – 4470)	1558 (27.6–3088.4)	411.8 (363.4–460)	2782.6 (71.7 – 5493.4)	2.71	0.175
Sympathetic Nervous System index	–0.566 (–1.4–0.27)	–0.14 (–0.88–0.60)	0.94 (0.39–1.5)	–0.30 (–1.6–1.0)	7.82	0.036
Parasympathetic Nervous System index	1.430 (–0.63–3.5)	0.122 (–0.84–1.1)	–1.176 (–1.4–(–0.99))	1.580 (–0.86–4.02)	11.44	0.028
Stress index	4.02	3.88	7.33	3.68	15.40	0.017
	(1.7–6.3)	(2.5–5.3)	(6.7–8.0)	(–0.11–7.5)		

Source: Authors.

The SDNN index showed no significant differences across BL, MD-1, MD-3, and MD-5, but significant differences were found comparing BL, MD1, and MD-3 (F(2, 8) = 6.75 p = 0.019, mean difference 22.3 ms, p = 0.0422) indicating decreased heart rate variability due to increased sympathetic activation. The overall SDNN mean was 103.3 ± 42.09 ms with a 40.7% variation. The pNN50 analysis revealed a significant linear trend from BL to MD-3 (t = –4.1105, DF = 4, p = 0.0147, within-subjects effects F(2.000, 8.000) = 7.91, p = 0.013), with a mean difference of 18.15%, p = 0.0442 and a 38.7% variation.

The RMSSD showed a negative but non-significant trend (t –2.6768, p = 0.0554), with no significant differences between mission days. The R-R Triangular index demonstrated significant within-subject differences between baseline and MD-3 (t –3.6954, p = 0.0209, mean difference 5.586, p = 0.0209), but the NN interval interpolation was non-significant. The Sympathetic nervous system index differed significantly on MD-3 (t = 4.7323, p = 0.0091 from baseline, mean difference 1.508 (CI95% 0.623 – 2.393)), and vagally mediated changes were lower (mean difference –2.606 (CI95% -4.745 to –0.467)). The stress index showed a significant mean difference of 3.3 (CI95% 0.967 – 5.652, $t(4)$ = 3.924, p = 0.0172), with an overall mean of 3.85 ± 2.72 and a variation of 70.69%.

Frequency-domain results (FFT spectrum)

We utilized Fast Fourier Transform –FFT– to partition heart rate variability into Very Low Frequency –VLF–, Low Frequency –LF–, and High Frequency –HF–, comparing differences between baseline, MD-1, MD-3, and MD-5 (Table 2). Frequency-domain analysis via repeated measures ANOVA with Greenhouse-Geisser correction found no statistically significant differences across all measurements and pairwise comparisons.

Table 2. *Frequency-domain results of the heart rate variability among baseline, mission day 1 (MD-1), mission day 3 (MD-3) and mission day 5 (MD-5).*

Variable	Baseline	MD-1	MD-3	MD-5	F	p
Power VLF (log) CI95%	6.364 4.690–8.037	6.082 5.281–6.882	5.078 4.63–5.51	7.260 5.502–9.017	3.66	0.114
Power LF (log)	8.584 7.261–9.906	8.022 7.273–8.771	7.062 6.68–7.44	8.98 7.25–10.7	3.66	0.105
PowerHF (log)	7.622 6.762–8.481	7.102 6.554–7.649	6.036 5.36–6.71	7.88 6.56– 9.19	5.32	0.061
VLF (%)	7.550 3.89–11.20	9.338 6.936–11.73	9.330 5.96–12.69	11.740 8.93–14.5	3.08	0.134
LF (%)	65.910 56.48–75.33	64.114 55.64–72.58	65.780 56.4–75.1	65.60 58.7–72.4	0.088	0.898
HF (%)	26.5080 15.07–37.94	26.516 16.43–36.59	24.88 13.1–36.6	22.64 14.6–30.6	0.31	0.701
LF/HF	2.878 1.12–4.63	2.714 1.13–4.29	3.066 1.25–4.87	3.140 1.87–4.40	0.18	0.810

Source: Authors.

Non-linear results

In our non-linear analysis, the unpredictability index combines frequency and time domain measurements to represent autonomic balance between baseline and mission days. No significant differences were observed, as detailed in Table 3.

Table 3. *Non-linear domain results of the heart rate variability among baseline, mission day 1 (MD-1), mission day 3 (MD-3) and mission day 5 (MD-5).*

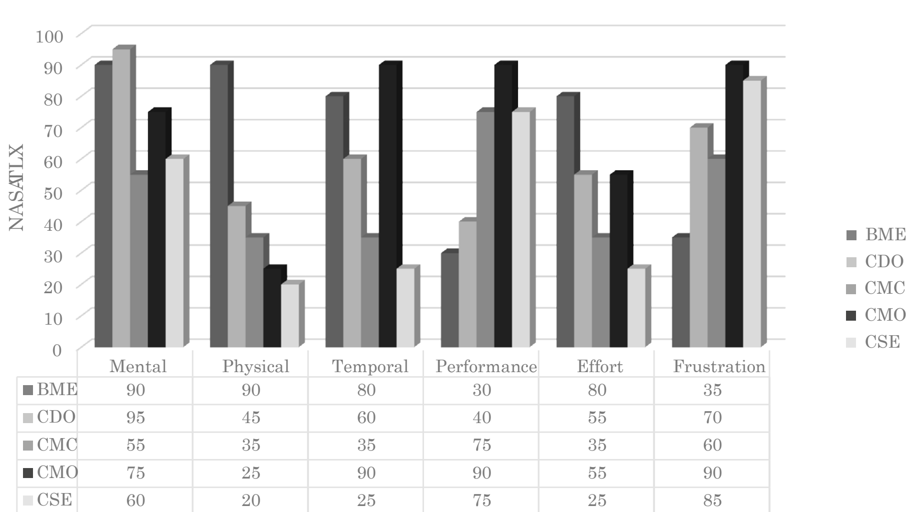
Variables	Baseline	MD-1	MD-3	MD-5	F	p
SD1 CI95%	73.21 19.49–126.9	48.12 28.31–67.92	24.90 16.63– 33.1	83.60 28.58–138.61	3.0	0.135
SD2	111.08 59.24–162.9	82.37 64.54–100.2	56.88 47.32–66.43	123.60 63.43–183.7	3.47	0.120
SD2/SD1	1.67 1.14– 2.21	1.77 1.43–2.11	2.38 1.69–3.07	1.63 1.13–2.13	2.89	0.118
Approx. Entropy	1.33 1.05–1.60	1.25 0.96–1.53	1.25 1.06–1.45	1.14 0.90–1.38	1.69	0.251
Sample Entropy	1.49 1.15–1.84	1.28 0.83–1.73	1.26 0.96–1.56	1.13 0.79–1.46	3.73	0.079
Alpha 1	1.24 1.03–1.44	1.19 1.06–1.32	1.30 1.05–1.55	1.13 0.97–1.29	1.25	0.336
Alpha 2	0.45 0.21–0.69	0.50 0.36–0.65	0.51 0.43to 0.58	0.58 0.48–0.67	1.61	0.273

Source: Authors.

Workload

Post-emergency workload was evaluated using the NASA-TLX. The six normally distributed domains are as follows: effort 50 ± 21, frustration 68 ± 22, mental demand 75 ± 17.6, performance 75 ± 17.6, physical demand 43 ± 28, temporal demand 58 ± 28 (Figure 2). The overall workload estimation varied among crewmembers: BME 67.5, CDO 60.8, CMC 49.2, CMO 70.8, CSE 48.3. The CMO's increased workload likely stemmed from high scores in temporal demand, mental demand, and frustration due to ambiguous MCC information during emergencies.

Figure 2. *NASA-TLX scores after the emergency response from coronal mass ejection and micrometeorite impact on the lunar habitat on MD-3.*



Source: Authors.

Weighted linear regression showed low activation of the sympathetic nervous system correlating with better performance ($F(1, 3) = 18.9681$, $p = 0.0224$, R2 = 0.8634). Reduced parasympathetic tone showed negative linearity with perceived physical demand during emergencies ($F(1, 3) = 520.1148$, $p = 0.0002$, $R^2 = 0.9943$). There was a positive linear relationship between subjective mental demand and logarithmic low-frequency HRV oscillations ($F(1, 3) = 418.8876$, $p = 0.0003$, $R^2 = 0.9929$) and LF power ($F(1, 3) = 138.096$, $p = 0.0013$, $R^2 = 0.9787$).

Sleep

Crewmembers exhibited no sleep disorders, with baseline PSQS (3.8 ± 1.64), ESS (6 ± 1.2), SP (1.4 ± 0.55), and KSS (1.6 ± 0.89) scores within normal limits. During the five-day pre-habitat jetlag period, SP rated 1.73 ± 0.74 and KSS 2.27 ± 1.33. Actigraphy data demonstrated total sleep time (9.1h ± 0.61), restful sleep (8.1h ± 0.56), restless sleep (2.5h ± 1.84). Repeated measures ANOVA with Greenhouse-Geisser correction revealed no significant differences in total sleep time, $F(2.138, 8.554) = 1.00$, $p = 0.411$, restful sleep, $F(2.334, 9.336) = 1.81$, $p = 0.215$, and restless sleep, $F(1.162, 4.649) = 3.47$, $p = 0.125$.

Positive affect and Negative affect (PANAS)

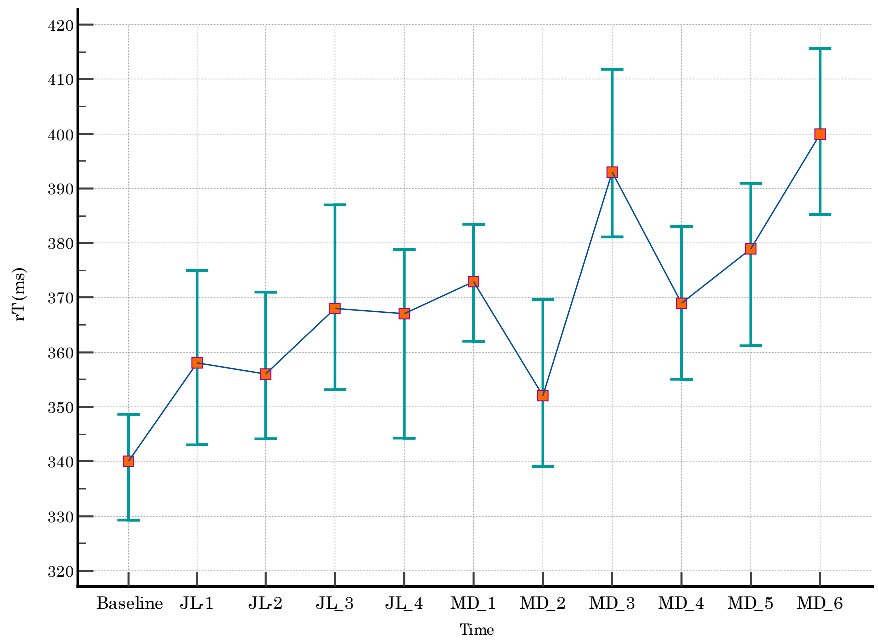
The impact of time on positive affect from BL to MD-5, analyzed using repeated-measures ANOVA, was not significant, F(1.427, 5.709) = 2.67, $p = 0.155$. Similar results were found for negative affect, F(1.300, 59.100) = 2.58, $p = 0.168$. Notably, MD-3 introduced considerable stress due to simulated emergencies, which disrupted the task sequence and required rapid problem-solving. The ensuing increase in sympathetic nervous system tone resulted in a higher baseline heart rate, a decrease in mean R-R interval, a negative LF trend, and a positive RMSSD trend.

One crewmember showed a notable increase in negative affect and decrease in positive affect from MD-3 onwards. However, HRV metrics did not significantly correlate with perceived affect.

Psychomotor vigilance test (PVT)

The Friedman test, comparing reaction time (rT) from baseline, 4 jetlag days (JL-1 to JL-4), and 6 mission days (MD-1 to MD-6), revealed a significant rT reduction from baseline, $F(1, 2) = 9.0601$, $p = < 0.00001$. Despite normal total sleep and restful time, crew members demonstrated a progressive slowing in simple rT, with an evident increase on MD-3, possibly due to circadian rhythms as seen in Figure 3.

Figure 3. *Simple reaction time (rT) in milliseconds during a 5-min PVT from baseline, jetlag and up to mission day 6.*



Source: Authors.

Neuropsychology

The neuropsychological results, illustrated in Table 5 and Table 6, encompass measurements in clinical psychopathology, cognition, and personality. The crew showed no clinical psychopathology, except a subtle decrease between MD-1 and MD-7, despite high levels of sleep disorder and state anxiety possibly linked to erratic sleep

Table 5. *Multiple comparisons of the reaction times from baseline up to MD-6. Minimum required difference of mean rank: 0.8031.*

Variables	Mean rank	Different (p<0.05) from variable nr
(1) Baseline	4.4756	(2) (3) (4) (5) (6) (8) (9) (10) (11)
(2) JL_1	5.5366	(1) (8) (10) (11)
(3) JL_2	5.5244	(1) (8) (10) (11)
(4) JL_3	6.0935	(1) (7) (8) (11)
(5) JL_4	5.7033	(1) (8) (10) (11)
(6) MD_1	6.1667	(1) (7) (8) (11)
(7) MD_2	5.1382	(4) (6) (8) (9) (10) (11)
(8) MD_3	7.0854	(1) (2) (3) (4) (5) (6) (7) (9)
(9) MD_4	6.0366	(1) (7) (8) (11)
(10) MD_5	6.7520	(1) (2) (3) (5) (7)
(11) MD_6	7.4878	(1) (2) (3) (4) (5) (6) (7) (9)

Source: Authors.

schedules and operational stress. Cognitive scores were low in visuo-construction, perceptual reasoning, and processing speed, possibly due to task-related stress and cognitive fatigue. Conversely, divided attention, motor speed, and visual memory performed above normative reference. Personality-wise, hostility and social anxiety were prominent, indicating potential tendencies towards anger and discomfort with others, counterbalanced by kindness and extraversion.

Shapiro-Wilk normality tests, related samples T-tests, and Wilcoxon signed-rank tests were used to compare psychopathological outcomes on MD-1 and MD-7, revealing no significant differences. Linear regressions were used to examine correlations between components across mission days. MD-1 psychopathology revealed hypersensitivity explained by LSB-anxiety (F = 307.200, p = 0.000, R^2 = 0.990) and obsession/compulsion from LSB-hostility (F = 21.823, p = 0.019, R^2 = 0.879), possibly due to new environmental stressors. No significant associations were found in the cognitive component on MD-5. In MD-5's personality component, neuroticism was explained by the hostility sub-scale (F = 18.870, p = 0.023, R^2 = 0.863), likely due to factors such as stress, sleep schedule changes, and task demands.

Table 6. *Descriptive statistics and interpretation of the clinical psychopathological component tests on day 1 of the mission (MD-1) and day 7 of the mission (MD-7)..*

Variable	MD-1		MD-7	
	M (SD)	Interpretation	M (SD)	Interpretation
LSB-50				
Psychoreactivity	51 (25.59)	Medium-high	44 (28.59)	Medium-low
Hypersensitivity	48 (22.24)	Medium-low	42 (28.19)	Medium-low
Obsession/compulsion	54 (24.84)	Medium-high	49 (21.90)	Medium-low
Anxiety	36 (10.83)	Medium-low	28 (13.03)	Medium-low
Hostility	42 (20.49)	Medium-low	34 (19.49)	Medium-low
Somatization	44 (24.34)	Medium-low	38 (17.88)	Medium-low
Depression	41 (18.16)	Medium-low	40 (24.23)	Medium-low
Strict sleep	67 (23.34)	Medium-high	60 (23.18)	Medium-high
Extended sleep	46 (19.81)	Medium-low	40 (18.37)	Medium-low
Psychopathological Risk Index	44 (18.84)	Medium-low	36 (15.16)	Medium-low
STAI				
STAI-State	36.8 (4.26)	Very high	34.8 (5.16)	Very high
STAI-Trait	16 (3.16)	Medium-low	16.4 (3.43)	Medium-low
IDER				
Euthymia state	7.8 (2.16)	Very low	9.4 (3.57)	Medium-low
Euthymia trait	7 (1.58)	Very low	7.2 (1.64)	Very low
Dysthymia state	5 (0.00)	Very low	6 (1.41)	Medium-low
Dysthymia trait	5.8 (1.09)	Medium-low	5.4 (0.89)	Very low

Source: Authors.

On MD-7, despite overall medium-low scores, LSB-hostility and dysthymia-state showed significant associations with psychological discomfort ($F = 605.000$, $p = 0.000$, $R^2 = 0.995$; $F = 696.200$, $p = 0.000$, $R^2 = 0.996$ respectively). Trait anxiety was linked with sleep disorders ($F = 23.519$, $p = 0.017$, $R^2 = 0.887$), even though its levels were medium-low, while high-level state anxiety showed no significant associations (Table 7).

Table 7. *Descriptive statistics and interpretation of cognitive and personality component tests on day 5 of the mission (MD-5).*

Variable	M	SD	Interpretation
	SDMT		
	52.40	16.90	Very high
	FCR*		
Copy	39	24.84	Medium-low
Reproduction	65	36.91	Medium-high
	NEO PI-R†		
Neuroticism	54.60	10.33	Medium
Extraversion	41.40	11.14	Medium-low
Opening	47.60	7.12	Medium
Responsibility	53	4.52	Medium
Kindness	48	6.63	Medium
Anxiety	51.40	7.53	Medium
Hostility	59.60	8.67	Medium-high
Depression	53.40	8.96	Medium
Social anxiety	58.20	12.07	Medium-high
Impulsiveness	47.80	7.56	Medium
Vulnerability	50.80	12.79	Medium
	WAIS IV		
Arrays	17	9.13	Medium-low
Symbol search	14	2.73	Very low

*Data in percentiles. †Personality test. Source: Authors.

Discussion and Conclusions

The demands of successful space exploration necessitate maintaining astronaut neurocognitive integrity (Stahn & Kühn, 2021) amid a diverse range of space flight risks (Antonsen et al., 2022). Our study examined physiological, clinical, cognitive, and personality shifts during a 7-day period of isolation in a controlled space analog environment. The findings resonate with those of previous studies and provide fresh insights into the multifaceted challenges posed by space missions.

Persistent high strict sleep sub-scale and state anxiety levels were observed, aligning with the findings of Leon et al. (2011). These conditions could be attributed to irregular sleep schedules and mission-related tension, reiterating the importance of robust sleep management strategies and stress reduction techniques in the preparation and execution of space missions (Mallis & DeRoshia, 2005).

Distinct personality facets, namely hostility and social anxiety, were prominent, reflecting the findings of Nicolas et al. (2016). This underscores the significant impact of the immediate social environment in isolation and highlights the necessity for comprehensive psychological support in astronaut training programs (De la Torre et al., 2012).

The medium-low scores on clinical scales could indicate the presence of fear and sensitivity, possibly associated with rapid adaptation to a demanding environment. This provides impetus for the development of adaptable and resilient astronaut profiles, capable of withstanding the rigors of space exploration (Johnston & Blue, 2021; Seedhouse, 2010; Steimle & Norberg, 2013). Cognitive scores were notably low in areas such as visuoconstruction, perceptual reasoning, and processing speed, consistent with the observations of Nicolas et al. (2016).

This decline might be due to sleep deprivation or stress related to isolation and confinement, necessitating further research to comprehend cognitive changes during long-term isolation, as suggested by Strangman et al. (2014). Environmental control variations were noted on MD-1 due to crew activities, which led to an increase in temperature and carbon dioxide levels. This observation mirrors concerns associated with real spaceflight environments and indicates the need for efficient countermeasures in space analog habitats. Fluctuations in HRV readings were found during isolation, possibly resulting from stress-induced sympathetic activity and reduction in vagal tone. These findings contribute to a growing body of literature that underscores the potential impact of acute stress on Heart Rate Variability –HRV– (Pagani et al., 1991). The effects of a combination of environmental and physiological variables on this interplay during analog space simulations, however, remain to be fully understood.

The results from our THOR space analog simulation highlight the indispensable role of sleep and mental well-being in ensuring optimal cognitive and psychological health during short-duration missions (Pundyavana et al., 2023). This underscores the importance of developing and implementing comprehensive sleep hygiene practices, operational stress management, and psychological support for future space missions.

The present findings contribute valuable insights into the potential psychopathological changes over the course of a mission, the complex interplay of cognitive and psychological factors during space missions, and the compounding effect of psychopathological factors over time.

For long-duration missions, the ability to manage monotony and loneliness becomes increasingly important. The observed results suggest the necessity to incorporate training programs focusing on enhancing coping strategies for these specific challenges in the preparation for longer missions.

Overall, these findings advocate for the development of comprehensive selection criteria and training protocols emphasizing sleep management, cognitive resilience, psychological balance, and coping mechanisms for monotony and loneliness. Implementing such strategies could enable us to better equip astronauts for the distinct challenges they may face, thereby ensuring their safety, productivity, and overall well-being during their time in space.

Our investigation has led us to valuable insights into the physiological and psychological dynamics during a 7-day period of isolation in a controlled space analog environment. We discovered that missions operating solely on space present a range of multifaceted challenges such as altered cognitive performance patterns, increased anxiety levels ,and disruption to sleep patterns–all requiring detailed management strategies.

We suggest robust sleeping practices and stress reduction techniques that take essential center stage during spacemen training programs. We conclude from our research that certain personality traits can manifest themselves under these conditions leading to an acute need for reliable psychological support programs amongst spacemen performing duties crucial to our well-being here on Earth.

Our study also highlights the significance of developing resilience within astronauts who do work under demanding conditions where adaptation is vital key amongst other protocols intended you ensure their safety, productivity while ensuring overall well-being during extended periods. Notably our findings are derived from simulated tests set across short durations albeit meaningful with wider ramifications necessitating further validation through more extensive studies ideally conducted under real-time conditions while taking into account selection criteria.

The authors of this research identified several limitations, including the short duration of the simulation, the low number of study subjects and the necessity for further studies under real conditions. It emphasizes the need for extensive validation to apply the findings broadly, considering the unique challenges of actual space missions. These limitations highlight the gap between simulated environments and the complexities of space exploration, suggesting areas for future research and the development of more effective space simulation scenarios.

Conflicts of Interest

Authors reports no conflicts of interest to report in relation to this study.

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Contributor roles

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