Abstract #:1641789

PUBLICATION TRENDS ANALYSIS: A NEW PERSPECTIVE ON ASSESSING RESEARCH OUTPUT

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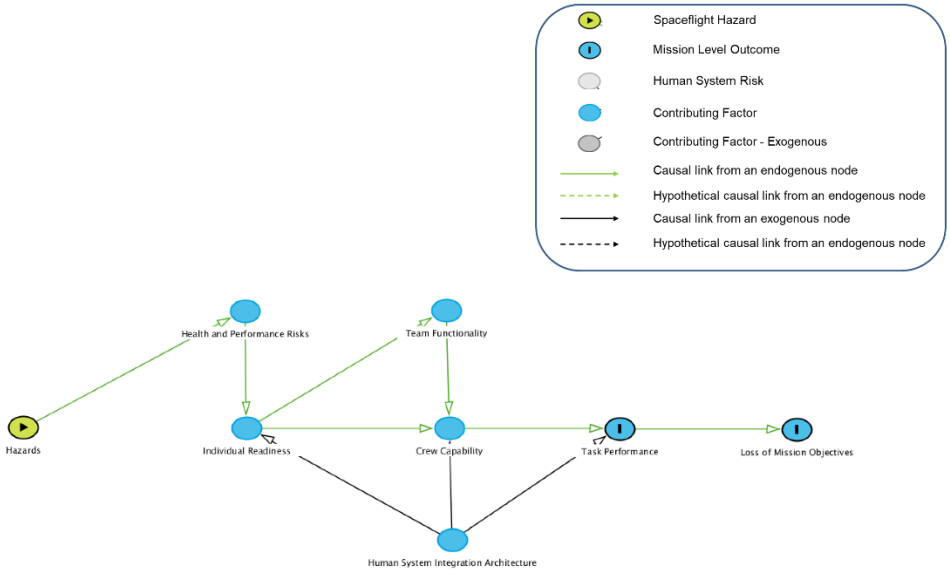
Figure 1. DAG Framework*



*Source: Directed Acyclic Graph Guidance Documentation. https://ntrs.nasa.gov/citations/20220006812

Table 1. Volume of Human Research Literature Curated in the NASA Task Book bibliography*

Type of publication	2018	2019	2020	2021	2022	2023
Abstracts	186	148	135	164	191	102
Peer-reviewed articles	283	249	330	289	234	146
Deduplicated peer-reviewed articles	194	171	220	188	180	107
Other articles	4	8	13	6	1	3
Papers from meetings proceedings	16	16	11	15	16	8
Book chapters	5	11	42	5	6	4
Dissertations and thesis	4	3	8	5	3	1
NASA technical documents	5	1	0	6	0	0
Patents	0	1	0	0	1	0

*Data cut-off Dec 31, 2023

Suppl. Table 1. Top Task Titles and Journals based on the highest number of journal articles published during 2018-2023

Task Title	No. of articles
Biomarkers as Predictors of Resiliency and Susceptibility to Stress in Space Flight	37
An Integrated Framework for Characterization of the Noncoding Genome and Epigenome in Astronauts	33
The Landscape of DNA and RNA Methylation Before, During, and After Human Space Travel	33
NSCOR: Mechanisms Underlying Charged Particle-Induced Disruption of CNS Function	25
Spaceflight Effects on Neurocognitive Performance: Extent, Longevity, and Neural Bases	25
Changes in the Neuroproteome Associated with HZE-Induced Impairment of Cognition	22
Space Biochemistry Profile	22
Center for Research on Cardiac, Vascular, and Acute Effects of Space Radiation	21
NSCOR: Space Radiation and Gastrointestinal Cancer: A Comprehensive Strategy for Risk Assessment and Model Development	21
NSCOR: NASA Specialized Center of Research on Carcinogenesis	19
A Non-intrusive Ocular Monitoring Framework to Model Ocular Structure and Functional Changes due to Long-term Spaceflight	18
Fluid Distribution before, during and after Prolonged Space Flight	17
Blood-based Multi-scale Model for Cancer Risk from GCR in Genetically Diverse Populations	17
HZE Particle Exposure-Induced Improvement of Pattern Separation in Mature Mice: Alterations in Mission-Relevant Behaviors and Neural Circuitry	16
Effects of Long-Term Exposure to Microgravity on Salivary Markers of Innate Immunity	15
Mechanistic Analysis of Particle Radiation-Induced Carcinogenesis Using Validated Mouse Glioma Models	15

Journal name	No. of articles
Life Sci Space Res	55
Sci Rep	49
Radiat Res	46
Front Physiol	31
Aerosp Med Hum Perform	25
JAppl Physiol	25
Int JMol Sci	21
Acta Astronaut	19
Hum Factors	18
npj Microgravity	17
Sleep	16

For the analysis period of 2018-2023, research on biomarker, genomics, and neurocognition produced the highest number of journal publications, followed by carcinogenesis, cardiovascular, and ocular.

Life Sciences in Space Research, Scientific Reports, and Radiation Research were the top 3 journals.

Table 2. Volume of Peer-Reviewed Journal Articles from the NASA Task Book Plotted Against Human System Risks Based on Details in Abstracts								**NASA HSRB Risk Report Roll-up (June 2023) In-mission Risk - Operations**							
Risks	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**	LEO < 30 D	LEO 30 D – 1 Y	Lunar Orbit <30 D	Lunar Orbit 30 D – 1 Y	Lunar O+S <30 D	Lunar O+S 30 D – 1 Y	Mars <1 Y	Mars 730-1224 D
Isolation and Confinement															
Behavioral Med	26	24	29	42	30	19	170								
Team	19	14	11	9	10	5	68								
Radiation															
Carcinogenesis	23	21	27	15	20	9	115								
Non-ionizing rad.	0	0	0	0	0	0	0								
Altered Gravity															
SANS	10	9	10	19	16	6	70								
Cardiovascular	16	10	18	10	15	7	76								
Muscle/Aerobic	6/3	12/2	6/0	3/0	3/0	3/0	33/5								
Bone fracture	14	6	13	6	4	2	45								
Renal stone	6	2	7	0	4	0	19								
Sensorimotor	22	5	9	10	11	6	63								
Crew egress	0	1	1	0	5	0	7								
Urinary retn.	0	0	0	0	0	0	0								
VTE concern	0	0	0	0	2	0	2								
Hostile Closed Environment															
Sleep loss	15	17	17	16	12	9	86								
Immune	10	8	10	6	8	2	44								
Microhost	5	4	6	9	6	3	33								
Hearing loss	0	0	0	0	0	0	0								
CO2	0	3	1	0	0	0	4								
Dynamic loads	0	3	1	2	0	0	6								
EVA	0	0	0	1	0	0	1								
Electrical shock	0	0	0	0	0	0	0								
Toxic exposure	0	0	0	0	0	0	0								
DCS	0	0	0	0	0	0	0								
Celestial dust	0	1	0	0	1	0	2								
Hypoxia	0	0	0	0	0	0	0								
Distance from Earth															
Medical cond.	1	9	10	11	13	15	59								
Food & Nutrition	3	1	14	4	10	3	35								
HSIA	3	1	0	4	3	5	16								
Pharm	1	0	0	1	0	0	2								
Multiple Hazards															
Multiple Risks	11	18	25	19	17	13	103								

Figure 2. Heatmaps of Research Concepts in Journal Articles Plotted Against Spaceflight Risks

	Research Topics/ Keywords in Journal Articles	Bmed	Team	Sleep	Immune	MicroHost	Nutrition	Medical	HSIA	Carcinogenesis	CVS	Muscle/ Aerobic	Bone	Renal stone	SANS	Sensorimotor
Altered gravity	Artificial gravity	1									2		1		1	7
	Cardiac changes	1		4	1			1			38	1				
	Muscle changes											23	7			
	Bone changes			1			1					2	25	3		
	Nephrolithiasis							1						10		
	Ocular changes	1					1	8							51	2
	ICP	3									1				14	2
	Fluid shifts	4									6				20	2
	Sensorimotor-related	4										1			1	24
Radiation	Cancer				3			1		36	1			1		
	Charged particles	65		5	8		2	2		49	14	1	5		2	4
	Radiation dose	8		1	3			1		17	2				1	
	Bystander effect	3								8	3					
	DNA damage/repair	2			1		1	1		29	1					
Closed hostile	Immune dysregulation	8			15	5	2	2		8	3	1				
	Infection				5	10		7								
	Microbiome	5			1	24	9	2					1			
	CO2	4					5								5	5
	Injury	3			1							1	1			
	Sleep/Circadian	4	1	53												
Isolated confined	BHP factors	49	16	12			1	1		1						
	Cognitive function	89	6	13	1			1		2	1					6
	Psychologic factors	13	5	2												
	Scheduling/Shift		3	11					2							
	Workload	3	1	1					2			1				
	Team dynamics	4	51						2							
	Performance	29	21	13			1		2		2	1			2	11

Figure 2. contd.

	Research Topics/ Keywords in Journal Articles	Bmed	Team	Sleep	Immune	MicroHost	Nutrition	Medical	HSIA	Carcinogenesis	CVS	Muscle/ Aerobic	Bone	Renal stone	SANS	Sensorimotor
Common factors	Aging	2			4			1		2	1		2			3
	CNS changes	67		5	3	2		3	1		2				12	14
	Countermeasures	17	2	9	4	2	4	2		7	9	4	3	2	13	6
	Biomarker	5		6	8	4		8		6	6	1	1		4	
	Diagnostics/Monitoring		1		3	1	1	24		1	4	1	1	3		
	Individual factors	1	1	8			2	1			3				1	1
	Genomics	1		2		13		3		15	3	1	2		1	
	Nutrition&Food	1		4	4		26				3	2	2		2	
	Metabolism			5		1	1	1			1					
	Endocrine	1		2				1					2			
	Exercise	2	2	1	8	1					3	8	3		1	
	Spaceflight stress	15		1	8	2			1		3		1			1
	Cell signaling				2		1			7	2		2		1	
	Inflammation	11			3		1	2		3	2		2			
	Oxidative stress	6		1		1	3			6	5	2	2		2	
	Autonomous system	1	6	1			1	6	2	1						
	Medications/Drugs	10		1	4	1	2	7		11	3	2	2			
	Treatment/Therapy	3		3	1	1		10		2	2	2	1	6		1
	Training	3	5	1				5			1					5
	HSI								10							

Heatmap of Research Topics Covered in Literature Related to Immune Risk

Research Topics or Keywords in Literature Related to Immune Risk	2019	2020	2021	2022	2023
Aging	0	0	2	2	0
Biomarker	2	3	2	1	0
Cancer	1	0	1	1	0
Cell signaling	1	1	0	0	0
Charged particles	2	2	1	2	1
CNS/Brain	1	1	0	1	0
Cognition	0	0	0	1	0
Countermeasures	2	1	1	0	0
Diagnostics/Monitoring	1	0	1	1	0
DNA damage/repair	1	0	0	0	0
Exercise	1	4	3	0	0
Hematopoietic	1	0	0	0	0
Immune dysregulation	1	5	3	5	1
Immune response	1	4	5	3	1
Immunomodulation	2	3	0	2	0
Infection	0	3	1	1	0
Inflammation	2	1	0	0	0
Injury	0	1	0	0	0
Lab/Biochemistry	1	0	0	1	1
Medical illness	1	0	0	2	0
Medication/Drug	0	3	0	1	0
Microbiome	0	0	0	1	0
Microgravity	0	2	0	0	0
Nutrition/Supplements	1	1	0	1	1
Omics	2	2	2	1	2
Radiation dose	1	0	1	1	0
Spaceflight stress	3	2	0	2	1
Treatment/Therapy	0	0	0	1	0
Vaccination	2	0	2	0	0
Viral reactivation	2	4	0	1	0
Immunology in literature related to other RISKS					
BMed Risk	1	1	2	1	1
Carcinogenesis Risk	1	4	4	0	0
Cardiovascular Risk	1	1	0	1	1
Microhost Risk	1	3	0	1	0
Muscle Risk	0	1	0	0	0
Medical Risk	0	1	6	0	0

Heatmap of Research Topics Covered in Literature Related to Sensorimotor Risk

Research Topics or Keywords in Literature Related to Sensorimotor Risk	2019	2020	2021	2022	2023
Aging	1	1	0	0	1
Adaptation	0	0	2	4	2
Artificial gravity	0	0	2	1	4
Charged particles	0	1	2	1	0
CNS/Brain	0	4	5	3	2
CO2	0	1	4	0	0
Cognition	1	0	3	2	0
Countermeasures	0	0	1	2	3
Fine motor control	0	0	3	1	1
HDBR	0	1	4	0	0
Intracranial pressure	0	2	0	0	0
Microgravity	1	1	1	1	2
Multisensory integration	2	1	2	1	0
Motion sickness	0	0	0	1	1
Neuromodulation	1	3	0	0	0
Ocular	0	0	2	0	0
Performance	1	2	3	3	2
Postural control/locomotion	4	3	7	8	2
Proprioception	1	0	1	0	0
Spatial orientation	2	1	3	3	2
Training	1	1	0	2	1
Vestibular factors	4	3	6	7	2
Vestibuloocular	1	0	3	3	2
Vision/gaze control	2	1	2	2	2

Heatmap of research topics covered in literature related to Behavioral Med Risk

Research Topics or Keywords in Literature Related to BMed Risk	2019	2020	2021	2022	2023
BHP factors	11	12	15	6	5
Bystander effect	1	0	1	0	1
Charged particles	11	13	22	13	6
CNS changes	15	15	18	13	6
CO2	1	1	2	0	0
Cognitive function	18	17	30	13	8
Countermeasures	0	2	8	5	0
DNA damage/repair	0	1	0	1	0
Exercise	1	0	0	1	1
Fatigue	0	1	0	0	0
Fluid shifts	3	1	0	0	0
HLU/HDBR	1	2	5	0	0
HSI	1	0	0	0	0
ICP	1	0	1	0	0
Immune	1	1	3	2	1
Inflammation	0	3	2	5	1
Medications/Drugs	2	3	3	2	0
Microbiome	1	2	0	2	0
Nutrition/food	0	1	0	0	0
Oxidative stress	1	2	1	1	1
Performance	4	6	9	3	4
Psychologic	2	1	5	4	1
Radiation dose	2	1	3	0	2
Sensorimotor-related	1	0	1	0	2
Sensory augmentation	0	0	1	1	0
Sleep	0	1	2	0	1
Stress	0	2	6	4	3
Treatment	0	0	1	1	1
Training	1	1	0	1	0
Workload	1	0	1	0	1
BHP assessed in literature related to other RISKS					
Sleep Risk	2	3	6	2	0
Team Risk	5	1	4	5	1

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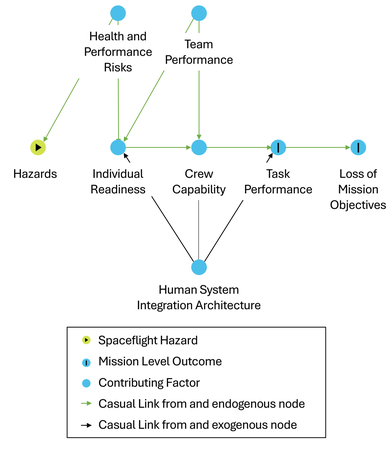
BACKGROUND

- Supporting the development of efficient countermeasures against spaceflight-related risks, NASA's Human Research Roadmap is a compendium of interlinked Risks, Gaps, and Tasks, along with the associated publications.[1] We believe that a **quantitative analysis of these publications may reveal new actionable insight on the research activities** supported by NASA's Human Research Program.
- **Directed Acyclic Graphs (DAGs)**, maintained by the Human System Risk Board (HSRB), are causal diagrams that demonstrate relationships between human system risks (Figure 1).[2] DAGs are intended to improve insight and communication of risks across the myriad of subject matter experts interested in human system risk reduction.
- We tested an **unconventional approach of mapping journal publications** indexed in NASA's Task Book **to risk concepts described in the DAGs** in an attempt **to reveal gaps and opportunities** for further research into reducing human system risks.

Figure 1. DAG framework



METHODS

- Our analysis focused only on peer-reviewed **journal articles** published during **2018-2023** and indexed under "**Human Research**" in the NASA Task Book.[3] Bibliographies were downloaded in Excel format by calendar year and **references were deduplicated**.
- Based on the **research and keywords** described in the abstracts, each article was (1) **assigned to one or more of the 30 spaceflight Risks** and (2) **tagged with several "research concepts" that we coined from the Nodes terminology** used in DAGs.
- We assessed the overall annual publication volumes and the number of journal articles for each Risk. We then **tried to recognize trends in research based on the frequency of the research concepts**.

RESULTS

Table 1. Volume of human research literature curated in the NASA Task Book bibliography*

Type of publication	2018	2019	2020	2021	2022	2023
Abstracts	186	148	135	164	191	102
Peer-reviewed articles	283	249	330	289	234	146
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Papers from meetings	16	16	11	15	16	8
Book chapters	5	11	42	5	6	4
Dissertations and thesis	4	3	8	5	3	1
NASA tech documents	5	1	0	6	0	0
Patents	0	1	0	0	1	0

Data cut-off Dec 31, 2023

- Annual publication volumes appear stable and range bound for the assessment period (Table 1). The spike in journal articles in 2020 during the pandemic may reflect greater researcher timeshare being devoted to paper writing than to activities requiring in-person collaboration. **A possible decline in journal articles in 2023** may be attributed to lag times in the publishing process or in recording the publications in the Task Book.
- Approximately 30% of peer-reviewed journal articles were tagged to multiple HRR Tasks, reflecting the integrated systems approach to developing countermeasures.
- **Top journals and Title Tasks** based on number of journal articles are shown in Suppl. Table 1 (Please scan QR code).

Table 2. Volume of peer-reviewed journal articles from the NASA Task Book plotted against Human System Risks based on details in abstracts

Risks	2018	2019	2020	2021	2022	2023	Total	NASA HSRB Risk Report Roll-up (June 2023) In-mission Risk - Operations: LEO < 30 D	LEO 30 D – 1 Y	Lunar Orbit <30 D	Lunar Orbit 30 D – 1 Y	Lunar O>S <30 D	Lunar O>S 30 D – 1 Y	Mars <1 Y	Mars 730-1224 D
Isolation and Confinement															
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Team	19	14	11	9	10	5	68								
Radiation*															
Carcinogenesis	23	21	27	15	20	9	115								
Altered Gravity															
SANS	10	9	10	19	16	6	70								
Cardiovascular	16	10	18	10	15	7	76								
Muscle/Aerobic	6/3	12/2	6/0	3/0	3/0	3/0	33/5								
Bone fracture	14	6	13	6	4	2	45								
Renal stone	6	2	7	0	4	0	19								
Sensorimotor	22	5	9	10	11	6	63								
Hostile Closed Environment*															
Sleep loss	15	17	17	16	12	9	86								
Immune	10	8	10	6	8	2	44								
Microhost	5	4	6	9	6	3	33								
Distance from Earth*															
Medical cond.	1	9	10	11	13	15	59								
Food & Nutrition	3	1	14	4	10	3	35								
HSIA	3	1	0	4	3	5	16								
Multiple Hazards															
Multiple Risks	11	18	25	19	17	13	103								

*This abbreviated table excludes Risks with <10 journal articles during this period. Scan QR code for the full table.

- Table 2 shows the volume of journal articles bucketed by year and tagged to human system spaceflight risks as well as HSRB's assessment status for these risks as of June 2023.
- By considering the **number of journal articles as a surrogate measure of research activity**, these data could help identify
  1. Areas where additional research is required for risks to reach an acceptable level or
  2. Extensively researched areas where higher publication numbers would be expected.
- For example, Sleep, Immune, and Microhost risks have a **similar HSRB assessment status**, while Sleep research has produced **a notably higher number of publications** than Immune or Microhost research.

Figure 2. Heatmap of research concepts in journal articles plotted against spaceflight risks

- Figures 2 shows a **heatmap of research concepts** from journal articles published during 2019-2023 **plotted against spaceflight risks** associated with the most publication activity. **Such graphical analysis could reveal research gaps or help identify new opportunities**. For example, **bystander (non-targeted) effects of radiation** have been studied mainly in cancer-related research and to a lesser extent in cardiovascular and BMed research. Thus, bystander effects **may be studied in relation to other risk systems**. Similarly, there may be opportunities to **leverage the extensive research** in biomarkers, genomics, diagnostics, and individual factors **to develop personalized medicine approaches for astronauts**.
- A **more granular analysis** can be performed **for each Risk**, using research concepts that are more relevant to that Risk and correlate with Nodes from its DAG. **Please scan the QR code to view heatmaps specific to Immune, Sensorimotor, and BMed risks.**

DISCUSSION

- Through this unconventional approach, we aimed to **introduce an alternative approach for researchers to analyze literature in their fields and draw conclusions based on their subject area expertise**, rather than make concrete recommendations for further research.
- **Research funding agencies and administrators** may adapt this approach to their planning and auditing activities.
- The **subjectivity** in interpretation and tagging of journal articles to research concepts **is a limitation of our approach**. Also, the analysis focused solely on journal articles curated in the Task Book bibliography, which may not be fully representative of the ongoing research activity. A **more detailed qualitative gap analysis** of literature would yield more granular and precise insight on research needs.
- Some of our **recommendations** from conducting this task are as follows:
  - Given the ongoing development of the **Mega DAG**, our approach could be adapted to **create a hyperlinked interactive tool**, where individual publications are tagged to one or more relevant DAG nodes and are easily retrievable for an on-demand comprehensive assessment of the risk status.
  - We noticed **keywords closely corresponding to DAG terminology** in a small proportion of publications. This practice should be encouraged to support the development of tools based on literature indexing.
  - A **bottom-up approach through literature analysis** may yield new insight into DAG structure and nomenclature. For example, the concept of attention/alertness may need coverage in either BMed, Sensorimotor, or Sleep DAG.

References

1. Human Research RoadMap. https://humanresearchroadmap.nasa.gov/evidence/
2. Directed Acyclic Graph Guidance Documentation. https://ntrs.nasa.gov/citations/20220006812
3. NASA Task Book Bibliography. https://taskbook.nasaprs.com/tbp/index.cfm?action=bib_search

NASA Human Research Program Investigators' Workshop 2024, Galveston, TX. February 13-16, 2024.