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PUBLICATION TRENDS ANALYSIS

A NEW PERSPECTIVE ON ASSESSING RESEARCH OUTPUT

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Bioviser Universal Research has considerable experience of working with biomedical researchers and clinicians in furthering human health. Our expertise lies at the intersection of medical research, data science, and scientific communications. There is tremendous untapped potential for leveraging our services to drive efficiency and foster innovation in your pursuit for advancing human health research for space exploration.

We aim to translate our deep expertise in patient healthcare and clinical research to support researchers in their quest to develop countermeasures against spaceflight risks. Our technolog-yenabled solutions can be used in real-time health monitoring and other public health applications.

We will leverage our decadal experience in the pharmaceutical industry to contribute meaningfully to space health research. We envision a complementary role alongside industry peers, contributing to the growth and diversity of the space health research ecosystem.

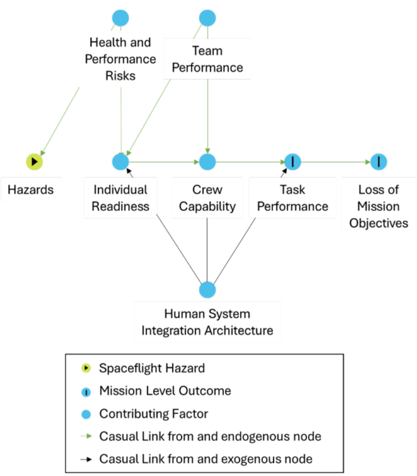
BACKGROUND

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.**

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 articles	194	171	220	188	180	107
Other articles	4	8	13	6	1	3
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.

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

- Areas where additional research is required for risks to reach an acceptable level or
- 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.

Table 2. Volume of Peer-Reviewed Journal Articles from the NASA Task Book Plotted Against Human System Risks Based on Details in Abstracts

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 –	Lunar O+S <30 D	Lunar O+S 30 D – 1	Mars <1 Y	Mars 730-1224 D
Isolation and Confinement															
Behavioral Med	26	24	29	42	30	19	170	Green	Yellow	Green	Yellow	Yellow	Yellow	Red	Red
Team	19	14	11	9	10	5	68	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Red	Red
Radiation															
Carcinogenesis	23	21	27	15	20	9	115	Green	Yellow	Green	Yellow	Green	Yellow	Yellow	Yellow
Non-ionizing rad.	0	0	0	0	0	0	0	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Altered Gravity															
SANS	10	9	10	19	16	6	70	Green	Yellow	Green	Yellow	Green	Yellow	Yellow	Red
Cardiovascular	16	10	18	10	15	7	76	Green	Green	Green	Green	Yellow	Yellow	Green	Red
Muscle/Aerobic	6/3	12/2	6/0	3/0	3/0	3/0	33/5	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow
Bone fracture	14	6	13	6	4	2	45	Green	Green	Green	Green	Yellow	Yellow	Green	Red
Renal stone	6	2	7	0	4	0	19	Green	Yellow	Green	Yellow	Green	Yellow	Yellow	Red
Sensorimotor	22	5	9	10	11	6	63	Green	Green	Green	Green	Red	Red	Green	Yellow
Crew egress	0	1	1	0	5	0	7	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red
Urinary retn.	0	0	0	0	0	0	0	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
VTE concern	0	0	0	0	2	0	2	Gray	Gray	Gray	Gray	Gray	Gray	Gray	Gray
Hostile Closed Environment															
Sleep loss	15	17	17	16	12	9	86	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Immune	10	8	10	6	8	2	44	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Microhost	5	4	6	9	6	3	33	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Hearing loss	0	0	0	0	0	0	0	Green	Green	Green	Yellow	Green	Yellow	Yellow	Yellow
CO2	0	3	1	0	0	0	4	Yellow	Yellow	Green	Green	Green	Green	Yellow	Yellow
Dynamic loads	0	3	1	2	0	0	6	Yellow	Yellow	Yellow	Yellow	Red	Red	Yellow	Red
EVA	0	0	0	1	0	0	1	Yellow	Yellow	Yellow	Yellow	Red	Red	Yellow	Red
Electrical shock	0	0	0	0	0	0	0	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow
Toxic exposure	0	0	0	0	0	0	0	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
DCS	0	0	0	0	0	0	0	Green	Green	Green	Green	Red	Red	Green	Red
Celestial dust	0	1	0	0	1	0	2	Gray	Gray	Green	Green	Yellow	Yellow	Gray	Red
Hypoxia	0	0	0	0	0	0	0	Green	Green	Green	Green	Green	Green	Green	Green
Distance from Earth															
Medical cond.	1	9	10	11	13	15	59	Green	Yellow	Yellow	Red	Yellow	Red	Red	Red
Food & Nutrition	3	1	14	4	10	3	35	Green	Green	Green	Yellow	Green	Yellow	Red	Red
HSIA	3	1	0	4	3	5	16	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Red
Pharm	1	0	0	1	0	0	2	Green	Green	Green	Green	Green	Yellow	Yellow	Red
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			
	CO_2	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
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
	Biomarkers	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							

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.**

Heatmap of Research Topics Covered in Literature Related to

BMed 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

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
Vestibulocular	1	0	3	3	2
Vision/gaze control	2	1	2	2	2

BMed 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

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.

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