# Ten-Year Strategic Plan for Space Science

# Report of the Space Health and Life Sciences Working Group

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# VISION STATEMENT

It is the year 2030. The last decade has seen a spectacular reinvigoration of human space exploration by Government space agencies, the likes of which has not been seen since the Apollo era of the 1960s. A sustainable human presence has been established in lunar orbit on the Gateway, an international collaboration which has now been operational and expanding progressively since the mid-2020s. Although not crewed continually, it provides a natural waypoint for missions to the lunar surface and a research platform that has served its purpose well as a proving ground for technologies that will see missions succeed even further into the solar system. Australian expertise in remote medical care and telemedicine has provided the technology for the modular medical bay aboard the Gateway which stands ready to provide care in the event of any emergency, a proud and uniquely Australian contribution to space exploration.

Since the Artemis 3 mission 6 years ago, when the first woman set foot on the moon in 2024, yearly lunar missions have become almost routine allowing the establishment of a permanent beachhead at the lunar south pole from which surface exploration of the Moon has been answering many questions about the origins of the inner solar system. A collaboration of Australian Universities and Industry have flown many life sciences experiments, not only to Gateway but down to the lunar surface under the umbrella of the Australian Virtual Institute for Space Health and Life Sciences. Now at the beginning of a new decade preparations are in place for the departure of the greatest and most momentous exploration mission in human history - to Mars. For Australia it is momentous too. Our world leading medical training programs, in particular in remote and extreme environment medicine, have been combined with space medicine training and moulded into the training pathway of choice for international physician astronauts destined for deep space missions. Graduates have already set foot on the lunar surface, but now Australia is proudly providing our very own crew medical officer on the first human mission to Mars. Artemis 8 will transport the crew to the Gateway to board their transit vehicle in preparation for departure, and then for the duration of the three year mission, Australian flight surgeons and biomedical engineers in Adelaide Mission Control will work side by side with colleagues in other centres around the globe and international agencies to provide 24 hour networked medical monitoring and care for the intrepid crew.

Alongside supporting the Moon mission, Australian Space Life Sciences and Health capability has also accelerated the emerging Space Tourism market. Facilities and centres established to support the growing Asian demand for Space Tourism have created new business opportunities, international collaboration and significant medical solutions in pre-flight, in-flight and post-flight monitoring and treatment with immediate commercial opportunities in the health sector.

In 2030, the success of Australia in the field of space health and life sciences has been achieved only through the decade-old plan to establish Australia as a global leader in space life sciences by stimulating research, establishing infrastructure, fostering local and international collaboration and generating spin-off products and services. The vision to provide a uniquely Australian niche biomedical capability to international human space exploration programs has been achieved. Those innovations and technologies have served to improve public health throughout the 2020s, and have generated considerable economic benefits for Australia, not only in the commercialisation of research developments, but also through reducing the economic burden of disease by improving health outcomes, particularly in elderly, underserved, remote and indigenous populations. Interest in STEAM subjects has never been higher in Australia and that has been largely thanks to the ability of space research and human space exploration by Aussies to inspire and engage Australia's healthcare and scientific workforce, and young people at all stages of their education.

# BACKGROUND ON TOPIC AREA

The human and biomedical sciences can and should be a key element of the future Australian Space Industry. There are three domains in which biomedical science is an important contributor. First, it is an enabler of human space flight, supporting commercial space tourism and future exploration missions. Australia's Government has committed funds to stimulate our industry to assist NASA and other international agencies with the Artemis and Moon to Mars Program, the missions that will return humans sustainably to the Moon in 2024, as a prelude to exploring Mars. Second, the scientific spin-off benefits that arise from human spaceflight programs will provide substantial economic and public health benefits to Australia through improved health care, the development of novel technologies by private industry, and stimulation of the academic and research sector. The emerging Space Tourism market may stimulate awareness of the health of humans in space, contributing to a demand for similar health monitoring and treatment technologies on Earth - initially customised to a high-net-worth clientele but with great ability to expand into a global mass market. Third, space is a unique microgravity laboratory that, independent of exploration programs, can be used to develop novel biomedical technologies which can be commercialised purely for the benefit of human health.

The advent of an Australian Space Agency has provided a much-needed organised framework and point of liaison to allow greater contribution by Australia to international research efforts. Australian researchers and clinicians have already been working in this field for some time (both at home and as expats working overseas for Space Agencies) and collaborating internationally, but independently, often unaware of programs being undertaken in other institutions elsewhere in Australia. Work has been undertaken by professional bodies and colleagues in the areas of space medicine education and in world leading provision of rural and remote medical care. Government organisations such as the Australian Antarctic Division have a strong track record of polar and extreme environment medicine research and collaboration with NASA in space analogue work. Multiple academic and clinical institutions around the country are involved in a wide range of space related disciplines, including fatigue and circadian physiology, somatosensory physiology, microgravity countermeasures, radiation microdosimetry and shielding, musculoskeletal effects of space flight, neurophysiology, nanotechnology, environmental monitoring, cellular biology, psychology/psychophysiology, and bioethics. Private industry is already collaborating with international space agencies, for example in the novel use of virtual reality for space applications, data analytics, wearable biomonitoring, and antimicrobial nanotechnologies. These existing areas of expertise position Australia well to expand its contribution to future human space flight programs through space medicine education, medical support for long-term exploratory missions, and developing countermeasures for the physiological challenges of space flight.

Key science questions come from existing human spaceflight programs and have been well defined. For example, NASA's Human Research Roadmap Integrated Path to Risk Reduction (HRR iPRR) is a top-level summary of some 230 knowledge gaps yet to be closed, which identifies 28 overarching risks with the long-term view of Mars exploration in mind. Table 1 lists the high-level and mid-level risks identified, and risks for which there is insufficient data to allow stratification.

*Table 1. Risks Identified by NASA's Human Research Roadmap.*

| RISK LEVEL (Likelihood vs Consequence) | | |
|---|---|---|
| **High Level Risk** | **Mid-Level Risk** | **Insufficient Risk Data** |
| Space radiation exposure and its relationship to cancer and degenerative diseases of the cardiovascular and central nervous systems | Injury from dynamic loads | Intervertebral disc problems |
| Cognitive and behavioural effects of spaceflight | Injury from EVA operations | Celestial dust exposure |
| Inadequate food and nutrition | Hypobaric hypoxia | Effects of medications in space |
| Team performance decrements | Decompression sickness | |
| Spaceflight Associated Neuro-Ocular Syndrome (SANS) | Altered immune responses | |
| Renal stone formation | Host-microorganism interaction | |
| Human system interaction design | Sensorimotor alterations | |
| Long term storage and stability of medications | Reduced muscle mass and strength | |
| Inflight medical conditions | Reduced aerobic capacity | |
| | Sleep loss and circadian misalignment | |
| | Orthostatic intolerance | |
| | Bone fractures | |
| | Cardiac rhythm problems | |

Previous reports[1], and indeed the research conducted for this strategic plan, indicate that Australia is already working to answer questions in many of these key areas. Capabilities will need to be developed or enhanced so that this work can continue and flourish. Importantly, deliberate and organised networking to increase connections domestically between researchers, and between researchers and industry will be key to this, as well as the establishment of international agency collaborations for training people and fostering research. Domestic capabilities may include things such as parabolic flight programs, head-down bed rest laboratories, short and long arm centrifuges, radiation laboratories, microgravity simulators, and hypobaric facilities. Establishment of a desert-based space analogue research program has the potential to supplement existing Antarctic analogue research to enhance understanding of psycho-social and human factors aspects of the risks identified.

The potential benefits to the Australian community and economy from a well-established space life science capability within the Australian Space Industry are enormous in revenue terms. The economic benefits come not only from commercialization of innovative technologies but from the

[1] Cable G, Ayton J et al. Space Life Sciences: Australia's Future Space Industry Capability. Submission to the Australian Space Agency Expert Working Group, Nov 2017.

application of those technologies to improve population health outcomes. The areas of greatest benefit for Earth-based medicine in the short term are likely to come from bone density research for osteoporosis[2], exercise development and reconditioning for people with musculoskeletal conditions[8], sleep and circadian physiology research[3], neuro-vestibular research for falls prevention[4], miniaturization of medical diagnostics, sensors and technologies[5], telehealth and remote medicine training and support, psychological care for isolated populations[6], antimicrobials to combat increasing antibiotic resistance[7], space-hardened pharmaceuticals and increased efficiencies in agriculture.

# Aim

The aim of this report is to provide a snapshot of Australia's current capabilities and resources in space life sciences and identify new opportunities and potential innovations for the coming decade mapped against priorities and key questions that international space agencies must address to achieve success in the human exploration of space.

# Methodology

Wide-ranging engagement with stakeholders from the space life sciences sector was sought by all members of the Space Health and Life Sciences Working Group. Using existing professional networks and snowball sampling techniques, respondents were invited by email to complete an online questionnaire. Face to face engagement was also employed during the Australian Space Research Conference in 2019 to provide information about the decadal planning process and invite participation in the survey. The survey requested demographic information regarding respondent's current professional positions. Previous, current and future planned work that may be relevant to space life sciences was explored together with any international space agency collaborations. Respondents were asked to identify Australia's niche capabilities in the field, and what might lead to the greatest benefits for human health generally ('impacts'). Their opinions were sought on key issues/challenges/gaps ('insight'), what should be achieved in the next decade to address these ('aspiration'), actions required to obtain these achievements, and what metrics could be used to measure success. Finally, respondents were asked to indicate from a list of key knowledge gaps identified by NASA's HRR, where they felt their work might contribute to closing those gaps, checking as many as required.

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[2] On current estimates by 2022, 6.2 million Australians over the age of 50 will suffer osteoporosis or osteopenia costing $3.84 billion. (Watts J, et al. Osteoporosis costing all Australians: A new burden of disease analysis – 2012 to 2022. Osteoporosis Australia, Deakin University, University of Melbourne, 2012)

[3] The total cost of inadequate sleep in Australia was estimated to be $66.3 billion in 2016-17. (Asleep on the Job: Costs of Inadequate Sleep in Australia. Sleep Health Foundation and Deloitte Access Economics Report, August 2017)

[4] In 2014-15, 1.4 million patient-days of hospital treatment were attributed to injurious falls. (Pointer S 2018. Trends in hospitalised injury due to falls in older people, 2002–03 to 2014–15. Injury research and statistics series no. 111. Cat. no. INJCAT 191. Canberra: AIHW)

[5] For example: Moore ST, MacDougall HG, Ondo WG. Ambulatory monitoring of freezing of gait in Parkinson's disease. J Neurosci Methods. 2008 Jan 30;167(2):340-8.

[6] The total disease burden rate in "remote and very remote" areas of Australia was 1.4 times as high as that for major cities in 2015. (Australian Burden of Disease Study: impact and causes of illness and death in Australia 2015. Australian Burden of Disease series no. 19. Cat. no. BOD 22. Canberra: AIHW)

[7] Antimicrobial resistance driven by the overuse and misuse of antibiotics shows little sign of abating in Australia and poses an ongoing risk to patient safety, with common pathogens becoming increasingly resistant to major drug classes. (Australian Commission on Safety and Quality in Health Care (ACSQHC). AURA 2019: third Australian report on antimicrobial use and resistance in human health. Sydney: ACSQHC; 2019)

Demographic information was summarised, and qualitative responses were assessed using thematic analysis and then tabulated using Microsoft Excel software.

# Results

N=50 respondents completed the online survey. Two respondents were excluded from the analysis – one who responded twice to the same survey, and the other who did not provide serious responses to the questions. This left a final sample of N=48 on which the analysis was conducted.

Respondents came from a broad range of scientific disciplines summarized in Table 2, with 51% working in academia, 17% in clinical roles, 12% in each of Government and professional organisations, and 8% from industry.

*Table 2. Disciplines represented among respondents.*

| **Clinical Medicine** | **Sciences** | **Allied Health** | **Engineering** |
|---|---|---|---|
| Aerospace medicine | Astrophysics | Psychology | Aerospace |
| Space medicine | Zoology | Physiotherapy | Engineering |
| Hyperbaric medicine | Flow chemistry | Nutrition | Habitat design |
| Family medicine | Space biology | Telehealth technology | Biotechnology |
| Emergency medicine | Microbiology | Health education | |
| Rural /remote medicine | Physiology - exercise | Human factors | |
| Public Health | Physiology - vascular | Biomechanics | |
| Anaesthesia | Medical physics | Biosecurity | |
| Psychiatry | Archaeology | | |
| Immunology | Physics | | |
| Health and medicine | Physiology - comparative | | |
| Radiation oncology | Biochemistry | | |
| Bioastronautics | Neuroscience | | |
| | Nuclear and radiation science | | |
| | Computer science | | |
| | Mathematics | | |
| | Chemistry | | |

Work currently being undertaken by respondents relevant to space health, life sciences and human spaceflight was most commonly reported as gravitational physiology, electromagnetic and space radiation, biomedical devices and monitoring, and virtual/augmented reality devices. The range of current work is summarized in Figure 1. Seventy-seven percent of respondents reported current or previous collaborations with international space agencies, most commonly NASA (30%), ESA (21%) and DLR (12%). Only 23% of respondents reported previously commercializing SHLS research developments that could benefit the health of human populations, however 56% planned to do that in the future.

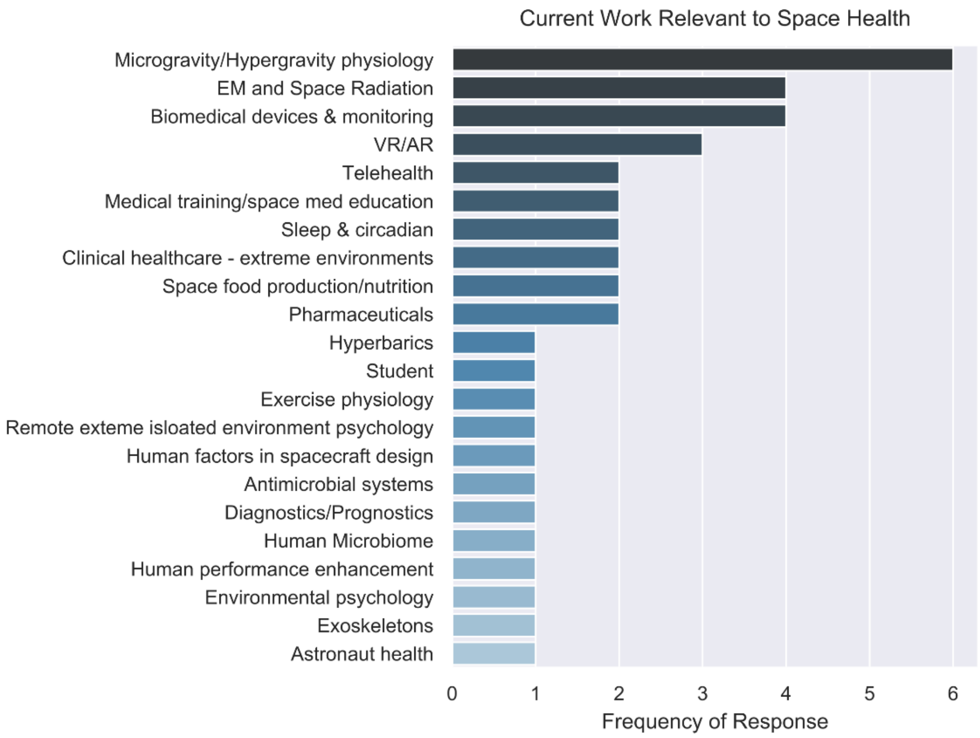


*Figure 1. Current work being undertaken by respondents.*

The responses to 5 key questions listed below, posed by the Australian Academy of Science, are summarized in Table 3. Summary of key issues/challenges/gaps ('insight'), what should be achieved in the next decade to address these ('aspiration'), actions required to obtain these achievements, impacts, and measures of success.

- Can you provide **insights** into the current main issues, challenges and knowledge gaps in space medicine and life sciences?
- What capabilities and achievements should Australia **aspire** to develop in space health and life sciences over the next 10 years?
- What are the **actions** required to obtain these capabilities and achievements?
- In what area do you think developments in space life sciences and health could have beneficial **impact** on the health of the Australian population?
- What **metrics** could we use to quantify the success of space health and life sciences programs?

*Table 3. Summary of key issues/challenges/gaps ('insight'), what should be achieved in the next decade to address these ('aspiration'), actions required to obtain these achievements, impacts, and measures of success.*

| Insight | Aspiration | Actions | Impacts | Metrics |
|---|---|---|---|---|
| Radiation beyond the Earth's magnetosphere | Increased research capacity into the effects of space radiation, with facilities and infrastructure to support research into biological effects, monitoring and countermeasures. Provides monitoring and countermeasures to future missions. | Australian radiation research laboratories conducting radiobiological research for space application. Foster collaboration between researchers and disciplines. | Understanding radiation effects on cardiovascular and neurodegenerative diseases<br><br>Improved nuclear medicine techniques<br><br>Protection of radiation workers and protection of astronauts. | Academic outputs<br><br>Technologies and techniques translated to healthcare<br><br>Research grants approved<br><br>Experiments flown to space. |

| Insight | Aspiration | Actions | Impacts | Metrics |
|---|---|---|---|---|
| Problems of altered gravity | Microgravity & hypergravity research, and development of countermeasures | Collaboration with international researchers.<br><br>Establish dedicated research facilities, programs and infrastructure to address these important priorities.<br><br>Private industry to be encouraged to establish infrastructure in collaboration with Government and universities | Microgravity mimics the process of ageing.<br><br>Deeper understanding of diseases of the musculoskeletal system, cardiovascular system, and neuro-vestibular system in space will aid in the treatment of patients on Earth. | Number of experiments flown.<br><br>Reduced costs to the national economy |
| On-board medical systems and telemedicine for Earth-independent operations. | Operational capabilities derived from expertise in remote and extreme environment medicine and telehealth used to support Moon to Mars missions. | Development of new medical devices, biomonitoring, robotics, AI, big data management, communications, and telehealth strategies. Miniaturization of diagnostics. | Better management and improved healthcare of isolated and remote communities, and better healthcare delivery systems through the application of space technology, saving time, transfer to tertiary centres, support for isolated practitioners. | Improved burden of disease statistics in rural and remote areas<br><br>Reduced patient transfers to tertiary referral centres, transportation costs, patient-days in city hospitals.<br><br>Australian technology chosen to fly operationally to space.<br><br>Positive astronaut health outcomes. |
| Collaboration between disciplines and the translation of research into useful applications | Developing partnerships and opportunities, and integration with global experts, through an Australian Virtual Institute for Space Life Sciences as a national centre of excellence. | Establish an Australian centre of excellence in the form of a Virtual Institute to provide a focal point and leadership for interdisciplinary collaboration among Australian institutions | A streamlined approach to facilitate access to international and domestic collaborators and funding sources specifically for the life sciences | International investment and numbers of collaborations<br><br>Successfully commercialized outputs |
| The physiology and psychology of isolation and confinement, including circadian disruption and immune dysregulation | Space analogue research capabilities and simulated environments – underwater, desert. | Link a consortium of Australian universities, Mars Society of Australia and Government agencies with international analogue programs to | Improved mental health outcomes for isolated populations.<br><br>Novel treatments for autoimmune diseases, infectious diseases, | Number of experiments flown.<br><br>Reduced costs to the national economy, disease prevalence, disease burden and |

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|---|---|---|---|---|
| | Providing deeper understanding of immunology, microbiology and the microbiome, and behaviours/psychological impact of isolated/confined environments. | establish an enduring desert analogue research facility.<br><br>Collaboration with NASA on NEEMO program.<br><br>Promote expertise at AAD as world-leading in the field, increased outreach to international agencies for collaborative research in Antarctica. | sleep disorders, and circadian dysrhythmia.<br><br>Improved performance of teams in the workplace, improved productivity and decreased healthcare costs. | numbers of patient-days in hospital over the next 10 years compared to current estimates. |

| Insight | Aspiration | Actions | Impacts | Metrics |
|---|---|---|---|---|
| Funding for research and development | Clear mandate for research | Ongoing Aust Space Agency support for research and industry, dedicated research funding streams/grants allocated for space life science research, space medicine star-ups | An increase of Australian based research and translation | Academic outputs<br><br>Dollar amount of funding and grants secured for research<br><br>Number of jobs created in the sector.<br><br>Numbers of researchers in relevant fields. |
| Suborbital flights for commercial tourism operations will become commonplace, yet there is limited experience with the physiological impacts of these flights on humans. | Australia is likely to become a popular destination for suborbital launches due to favourable geography and geopolitical stability. | Collaboration with international agencies and commercial companies, Australian Space Agency support and facilitation, infrastructure for micro- and hypergravity research, funding of dedicated research programs. | Increased public interest in health technologies derived for high profile space operations.<br><br>Appropriate regulatory approach and health/safety standards for commercial space passengers in Australia.<br><br>Contribution to safety of operations internationally. | Growth in commercial space flight sector, flight safety, incident and accident statistics, and adverse in-flight medical episodes and injuries.<br><br>Commercialised products spun off to the broader aerospace and health industry. |
| Life support systems and habitats to support long duration missions, including hypobaric environments, space suit design, and appropriate nutrition. | IVA/EVA suit development leveraging off existing work.<br><br>Using ag-tech and food science capabilities to develop sustainable nutrition and pharmaceutical sources suitable for space. | Newly established civilian hypobaric/hyperbaric facility supported to establish research programs in collaboration with international agencies.<br><br>CSIRO and UTAS/ADF nutrition laboratories establish research programs in space nutrition. | Environmental engineering systems improving life on Earth, in particular for rural/remote communities, isolated populations through waste management, recycling, water purification and treatment, bioregenerative systems, air filtration, toxin monitoring and biosecurity/infection risk.<br><br>Agriculture and food production in austere/arid environments addressing global food shortages and hunger. | Successful validation in terrestrial analogues, patents awarded and publications<br><br>International partnerships<br><br>Development of space nutrition laboratories<br><br>Successful translation of technologies to long duration missions, lunar and Martian environments. |
| Maintaining astronaut health and clinical management on long | Development of space medicine expertise and space medicine | Foster international training opportunities and exchange programs | Longer shelf life and more effective pharmaceuticals, | Number of graduates in STEM disciplines relevant to life sciences |

| | | | | |
|---|---|---|---|---|
| duration missions, including pharmaceutical use | training, and the training of physician astronauts.<br><br>Monitoring, diagnostics and advanced sensing. Capability to assist international partners monitor and support crewed missions.<br><br>Development of novel and space hardened medications. | to develop and maintain a skilled workforce.<br><br>Develop tertiary education programs on space medicine and health in Australia.<br><br>Recruit expertise internationally to assist in establishment. | potential new drug countermeasures for radiation protection, sleep, immune support, bone density, antimicrobial technologies and coatings.<br><br>The establishment and growth of aerospace medicine as a discipline in Australia. | demonstrating the impact of education outreach; numbers of Australian medical specialists trained/working in space medicine. Retention of graduates within Australia. Number of successful human missions with Australian input; favourable astronaut health metrics. |

| Insight | Aspiration | Actions | Impacts | Metrics |
|---|---|---|---|---|
| Australian citizens in space, while historically difficult to achieve and not prioritized, is becoming increasingly likely with commercial space and the democratization of space. | Foster Australian astronaut contribution to international agency or commercial missions. | MoUs with international space agencies or commercial organisations. Sovereign space medicine capability for astronaut selection and training. Extreme and space medicine training program for physicians. | National pride, inspiration for STEM study and research, sovereign capability. Australian research conducted by Australians. Niche expertise such as medical generalists provided to space programs as skilled astronaut physicians. | Missions flown. Increased effective Australian remote and extreme generalist healthcare professionals. |

Niche capabilities that respondents believed Australia could contribute to human spaceflight programs over the next decade are illustrated in Figure 2. Australia's expertise in rural and remote healthcare and telemedicine were commonly reported to be a niche strength.

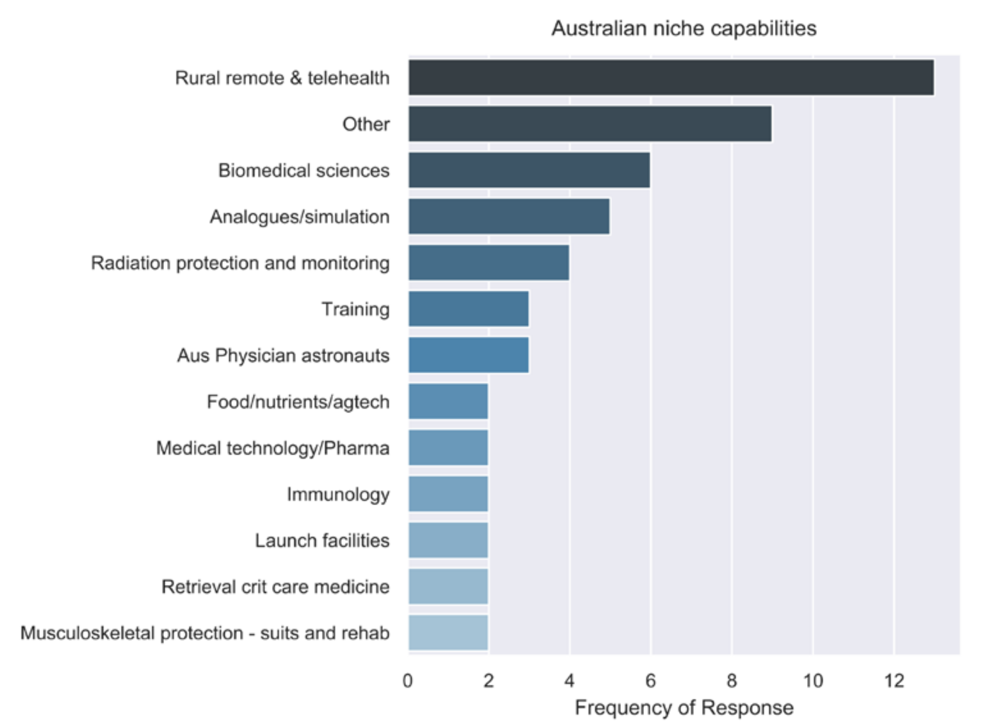


*Figure 2. Australia's niche capabilities.*

Figure 3 depicts graphically the number of respondents who identified that their current work may be relevant to key NASA Human Research Roadmap knowledge gaps. Respondents were asked to select as many as applicable. It is evident that Australian expertise covers the entire gamut of key research questions considered important for human space missions. In particular there seems to be an abundance of work that may contribute to knowledge of Human Factors and Behavioural Performance. Australia's unique experience with remote environments – from isolated communities in rural areas to isolated extreme environments in Antarctica - was also evident in the responses, with training of physicians and provision of medical care on exploration missions commonly identified.

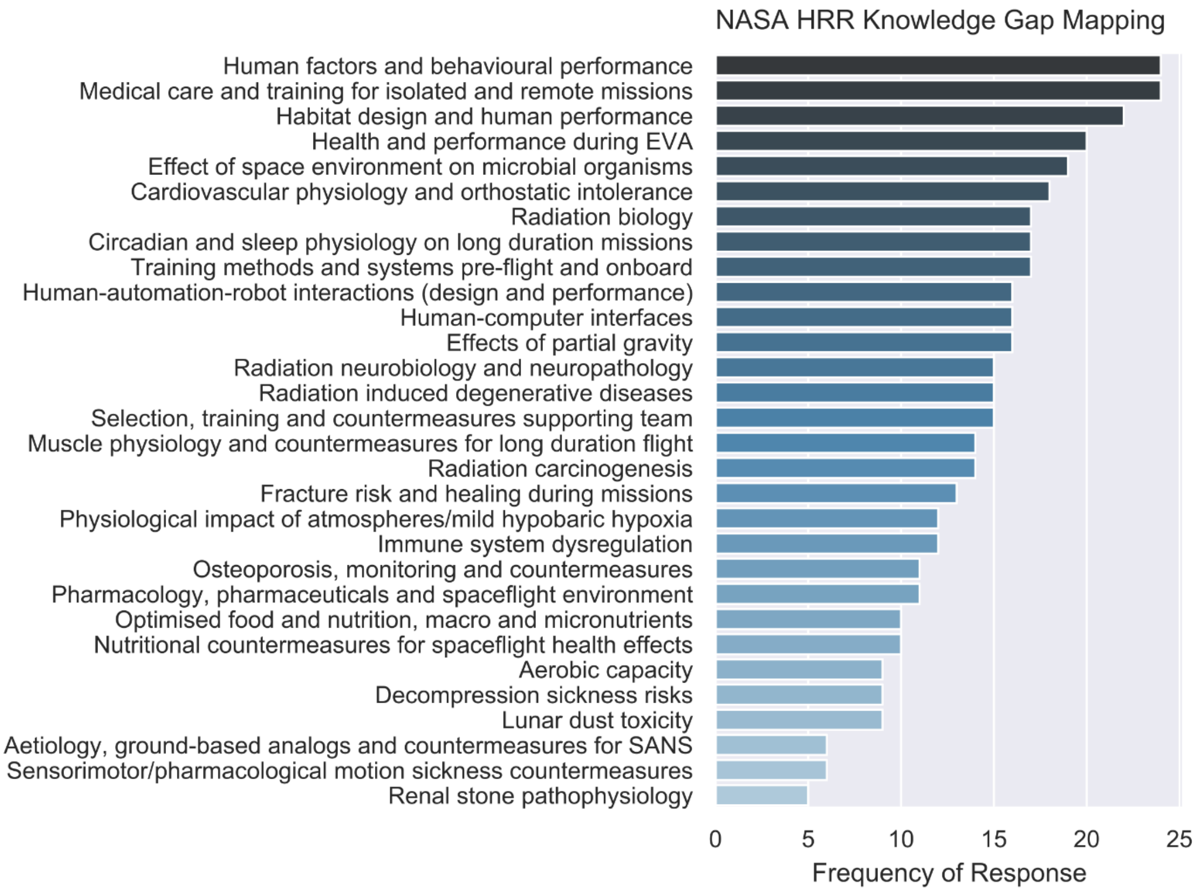


*Figure 3. Mapping of respondent expertise to NASA HRR knowledge gaps.*

# Recommendations

- **Prioritize funding** for health and life sciences - a common theme and clear message from the survey, recognising that returns on this investment in terms of the jobs created and the reduced economic impact of disease in the population are likely to be substantial.
- **Establish a Virtual Institute** of Space Health and Life Sciences fostering domestic and global multidisciplinary research collaboration, ensuring maximum effective translation of research from space for the benefit of the Australian community. Additional roles include developing human mission and astronaut health support through provision of clinical space medicine. Working side by side with the ASA, it provides a point of liaison and coordination with the biomedical community and international agencies.

- **Foster education and training**, through the establishment of international exchange programs, tertiary and postgraduate courses, and astronaut physician training. The survey showed that an Australian astronaut with these niche skills contributing to human missions would inspire and galvanise the nation behind the space program.
- **Prioritize and grow research** in the areas of:
    - **Radiation**, where a significant body of expertise already exists. This capability should be leveraged to help solve a range of key knowledge gaps including cognition, behaviour and health.
    - **Microgravity,** in particular musculoskeletal and neuro-vestibular physiology, where the biggest population health benefit can be derived from innovation and where dedicated facilities, human centrifuge, head-down bed rest laboratory and parabolic flight would greatly enhance capability.
    - **Life support systems**, photosynthetic bioregenerative environmental systems to provide innovative solutions to problems of agriculture and nutrition, water recycling, microbial countermeasures, and waste management.
    - **Suborbital flight** physiology and safety, spinning-off into a potentially lucrative commercial space tourism market.
- Leverage existing expertise in delivery of healthcare and training for r**emote/extreme environments** to provide medical systems and clinical support to exploration missions. Research and development to support these techniques for space will improve the lives of rural, remote and indigenous Australians.
- **Develop leapfrog telemedicine technologies**, for imaging, patient monitoring and AI diagnostics, with capabilities for clear transmission and analysis of big data for space mission health care, and 21st century healthcare of isolated patients on Earth.
- Establish a **desert analogue research facility,** leveraging an extensive body of work done to date, and capitalising on opportunities presented by international programs (such as AMADEE). Analogue environments exploring the physiology and psychology of isolation and confinement, human factors and psycho-social risks, are key NASA knowledge gap areas with many of our researchers already involved. It was identified by respondents as an important Australian contribution over the next decade and identified as a niche strength.

# CASE STUDY 1

*Musculoskeletal conditions were the leading cause of non-fatal disease burden in Australia in 2015, representing 25% of cases[8]. The following case study demonstrates how translation of research from space medicine can significantly improve the economic and social impact of such diseases.*

## Benefits of Space Medicine Research for Terrestrial Applications in Rehabilitation

Research on astronauts can benefit patients with conditions affecting the neuromusculoskeletal system and vice versa, as both face the challenge of managing the effects of disuse. Deconditioning in astronauts after spaceflight is a useful model for studying interventions for optimal recovery, as changes occur relatively rapidly and without the complication of underlying pathology seen in musculoskeletal and neurological disorders, where the effects of disuse are difficult to isolate. Physical inactivity is a major problem in the general population, despite the well-known benefits of exercise, causing public health and economic concerns in Australia and worldwide.

The effects of microgravity on the cardiovascular, musculoskeletal and neuro-vestibular systems are well documented. Changes in the neuro-musculoskeletal system include bone loss, muscle weakness (particularly postural muscles), reduced muscle mass, impaired motor control and balance and increased risk of lumbar disc pathology. As space missions will involve excursions on planetary surfaces, such as on Mars, challenges to the human body and requirements for effective postflight reconditioning need to be better understood by learning from existing knowledge and further research. For future exploration class missions to other planets, an additional phase of postflight reconditioning will be required following deep space cruise to the destination, to enable safe and effective exploration on a planet's surface. Effective and safe performance during surface planetary excursions on Mars following long duration flights at 0G will require preparation through specific functional exercise programmes on board prior to landing. Optimal reconditioning and preconditioning programmes for long duration missions have yet to be established.

There are three phases of mission cycles requiring the care of a multi-disciplinary medical team: preflight, inflight and postflight. The medical team includes specialists in medicine (flight surgeons), psychology, biomedical engineering, nutrition, physiotherapy and sports science. Implications for rehabilitation of the terrestrial population can be gained from these programs. Drawing on similarities with conditions seen in terrestrial populations may help inform postflight reconditioning, e.g. low back pain, where the distribution of trunk muscle atrophy is similar to that in microgravity. Comparisons have been drawn between the effects of microgravity and ageing, but the greater challenges ahead resulting from longer missions and new environments may benefit from drawing on the challenges and rehabilitation strategies in other terrestrial clinical conditions involving deconditioning, such as neurological conditions and critically ill patients in intensive care. At the other end of the spectrum, reconditioning of astronauts may benefit from adopting physical and psychological strategies for achieving optimal performance in athletes in elite sports. Measures such as astronaut-specific performance testing and movement quality, and motor control strategies to improve these aspects of function, may be of value but require further research.

In summary, translation of knowledge from spaceflight research and practice has implications for several areas of rehabilitation. Insights into space medicine will have more direct relevance, and even become a necessity for some terrestrial clinicians, as space tourism is set to become a reality.

[8] Australian Institute of Health and Welfare 2019. Australian Burden of Disease Study: impact and causes of illness and death in Australia 2015. Australian Burden of Disease series no. 19. Cat. no. BOD 22. Canberra: AIHW.

# CASE STUDY 2

## Antarctica as a Space Analogue

The Scientific Committee on Antarctic Research (SCAR) Expert Group on Human Biology and Medicine sets priorities for research on, and healthcare of, humans in Antarctica involving the fields of biomedical sciences, social and behavioural sciences, and medicine. Areas of particular interest include research into the effects of isolation, cold, altitude and light and dark. The use of the Antarctic as a space analogue for human research has been of interest to the international polar medicine community for some time.

Australia's Antarctic Program uses "Life in a Freezer" to offer a hi-fidelity space analogue for Operational Medicine, Training and Research for "ICE" environments – Isolated, Confined and Extreme.

**Isolated:** It can be up to 9 months (March–November) without access to evacuation in the event of an emergency. In addition, there is limited sophistication of medical support.

**Confined:** small populations of 16–25 expeditioners live together in shared habitats over winter.

**Extreme environment hazards**: Antarctic cold and wind, psychological stressors, 24 hours of polar night, terrain. These hazards are just as life threatening as those found in space and on other celestial bodies.

This challenging environment provides an analogue platform that has enabled Australian research in physiology, epidemiology, behavioural Health and psychology, and photobiology. It has provided clinical and operational medicine and training for extreme environment, and advanced telehealth and other technologies for training and clinical support of isolated populations.