

Why Space?

**The opportunity for Health
and Life Science Innovation**

Abbreviations

AI - Artificial Intelligence

ARIA - Advanced Research & Invention Agency

CAA - Civil Aviation Authority

CNES - Centre national d'études spatiales [CNES] | French government space agency

DLR - Deutsches Zentrum für Luft- und Raumfahrt [DLR] | German Space Agency at DLR

EAC - European Astronaut Centre

ESA - European Space Agency

EVA - Extravehicular activity

ISS - International Space Station

LEO - Low Earth Orbit

MOD - Ministry of Defence

NASA - National Aeronautics and Space Administration

NHS - National Health Service

NIHR - National Institute for Health Research

R&D - Research & Development

UKRI - UK Research & Innovation

UK Space LABS - UK Space Life & Biomedical Science Association

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Spearheaded by the research association, UK Space LABS (UK Space Life and Biomedical Science Association), our enormous appreciation goes to the membership and the current and previous executive committees for helping shape the community and drive this sector interface over the years.

An independent board from both the Health & Life Sciences and the Space Sectors was convened to advise the working group and review the submission and review process. Our thanks go to Professor Hagan Bayley (University of Oxford), Dr Tim Etheridge (University of Exeter), Libby Jackson (UK Space Agency), Dr Michael Adeogun (National Physical Laboratory), Dr Barbara Ghinelli (UKRI-STFC) and Dr Noriane Simon (UKRI-BBSRC).

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Executive summary

Why space? From unlocking the secrets of the universe to improving the understanding of our own homeworld, the benefits that the utilisation of space brings are only just being realised. This is particularly true for industry sectors, which are becoming growing 'users' of space including the Health & Life Sciences sector. This paper brings voices from within the Health & Life Science Sector and the Space Sector together to ask what are the possibilities of space? How can these be realised? What could this mean for our future?

Advances in remote monitoring are already providing information on disease outbreaks & natural disasters to aid response management. Growing ubiquitous connectivity is better enabling the provision of health management particularly in remote locations and utilisation of earth observation techniques are helping inform farming practices. These are just a few examples of how existing space assets are being used to support life on Earth.

Platforms ranging from small satellites (e.g. cube-sats) in Low-Earth Orbit (LEO), to dedicated laboratories on the International Space Station (ISS) are being utilised to advance our understanding of how certain fundamental processes adapt outside of our home environment. Studying how plants can create root structures in the absence of Earth's gravity to radiation effects on biological systems, are helping us understand not just how to enhance life on Earth, but also to provide the tools and knowledge for humanity's next age of exploration.

Through an open call process this paper has gathered >50 authored contributions from across the research community to help broaden our horizons of the still untapped potential for cross-sector innovation. As the global community seeks to recover post covid-19, the opportunity to galvanise our proven excellence in health and life sciences, and the strong investments in developing sovereign space launch capability, could ultimately become a powerful catalyst for future innovation and strengthen existing global ties.

Without the right funding, infrastructure, relationships and agreements, it is challenging for UK scientists to develop and sustain long-term research programmes in collaboration with the international agencies, principally ESA, and other commercial partners. Thematic chapters and underpinning individual author contributions highlight the need for bridging mechanisms between capability and access to overcome the barriers to doing space-related research for both exploration and terrestrial benefit.

The recommendations outlined in this paper draw from these diverse inputs to address the current challenges faced by this sector. From life science and human factors, to biomedical, AI and education there are key steps which can help facilitate the unlocking of this potential. Beyond dedicated funding, facilitated community building and knowledge exchange centres will be paramount to ensure a joined up and collaborative exploitation of this cross-sector interface, which can raise the UK's profile on the International stage. This paper is one of these steps and over time it could become an exercise to take stock, reflect on what other opportunities are on the horizon and create new R&D connections.

Beyond the Health and Life Sciences will be other sectoral opportunities, including in energy, materials chemicals and more. This paper provides a potential blueprint for these areas to explore their own 'Why Space' journey to ensure that the existing excellence in research is harnessed, cross-sector ideation is championed and new collaborative opportunities for innovation are fostered.

Professor Kate Robson-Brown
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Why Space for the Health & Life Science Sector?

Throughout this exercise, the question Why Space? has been asked. Reflecting on the diverse contributions received during the creation of this report, there are key potential benefits across scientific, economic and societal domains, including:-

- **New research & innovation:** Working at this interface between sectors provides a vehicle for cross-fertilisation of ideas. Bringing together people from different fields, offers the opportunity to drive innovation from discovery science to technology developments.
- **Growing the Space Economy:** The UK Government has ambition to grow its sovereign launch capability and share of the global space market by 10% by 2030. Through empowering the Health and Life Science ecosystem, one of the largest industrial sectors (from researchers and innovators, to investors and policy makers), with the knowledge of the added value of space, this will support the growth of users for these developing space assets and platforms.
- **Supporting other Government Priorities:** This report advocates the benefits that can be realised by extending this Government's ambition for space to include Space Life and Health Sciences. These areas also provide additional opportunities to support Government priorities from the Government R&D roadmap to the Integrated Review.
- **Potential terrestrial spin outs:** There are numerous direct and indirect downstream applications of space assets and human space flight research in the UK. These include benefits for a range of terrestrial health and life sciences sectors ranging from terrestrial pharmacology through to downstream applications of satellite Earth Observation.
- **Supporting Human Spaceflight:** As commercial space flight launches in the UK, there will be a greater need for UK trained space health care practitioners to support the passengers and crew pre, during and post flight. The GMC training pathway for Aviation & Space Medicine aims to address this.
- **Informing new treatments and clinical practice:** The Covid-19 pandemic has highlighted the need for innovation and horizon technologies from different sectors including the space health domain. Telemedicine research is a prominent part of human spaceflight research as it enables remote monitoring of astronauts and has been an invaluable asset for healthcare provision during the pandemic in the NHS. The digital health innovation in the space sector compliments the Topol review which focuses on building a NHS digital health workforce in the UK.
- **Stimulate careers and STEM:** Space life sciences is an inspirational area with the potential to stimulate growth, and encourage the next generation to engage with STEM subjects. These students will be the future workforce that drive forward STEM areas such as engineering, physics, medicine and more.

Key Recommendations

In order to harness the interface between the Space and the Health & Life Science Sectors to foster new research, innovation and translational activities, this report makes six recommendations:-

- **Harness the innovation opportunity from existing research portfolios:** Establish dedicated funding pilots with funders of Health and Life science research, in order to galvanise existing scientific capital on translational activities with space. For example, following the 2020 UKRI deep dive into space research funding, the establishment of a cross-UKRI Space working group, provides an opportunity to consider how funding in this area might be better supported and extended to include space related Health & Life Science research.
- **Create a proof of concept/ catalyst program for Industry:** To de-risk industrial R&D, facilitate the growth of the market opportunity and the commercialisation activity with space, a catalyst-like programme is recommended to drive an innovation pipeline. This would in turn stimulate the UK's launch and provider network, working with the UK Space Agency, by growing a sustainable customer base.
- **Fund high-risk high-reward thematic centres:** In keeping with the UK Government's renewed interest in high-risk, high-reward research and innovation and inspired by the success of NASA's Translational Research Institute for Space Health, set up at least three UK challenge-led R&D centres. These would provide opportunities to support Government priorities to deliver an R&D based future economy, contributing to the UK's position as a science superpower and in line with ambitions articulated in the creation of the Advanced Research & Invention Agency.
- **Inspire careers in the Health & Life Sciences:** The development of educational programs and outreach opportunities to promote new and existing career pathways in the Health and Life Sciences, particularly those associated with the Space Sector, should be pursued. It is envisioned that these activities will further encourage and enthuse the next generation of scientists, engineers, teachers, healthcare professionals, and astronauts.
- **Establish a dedicated knowledge exchange infrastructure:** This would enable knowledge exchange activities at various stages, from early research through to potential commercial and industry applications. This will support engagement with a broad customer base who might benefit from accessing knowledge in relation to space economies and terrestrial benefit, which can help to grow the customer base for future space and lunar economies.
- **Join the International Space Life Sciences Working Group (ISLSWG):** Currently several of the major international space agencies (Including NASA, ESA, DLR etc) sit on the ISLWG. By lobbying for the UK Space Agency to join this group, this will raise the UK's International Profile, connect its global leading expertise in Health and Life science research and foster other opportunities to enhance our representation with international groups, future exploration activities and roadmaps.

Opportunity and alignment to National and International roadmaps

The UK is a world leader in both the Space (particularly satellite systems and telecommunications), and Health and Life Sciences Sectors, which creates a unique opportunity to better understand and grow this powerful intersection¹.

From companies in the UK developing new imaging methods derived from space technology² to using satellite applications to support drone delivery of Covid-19 testing kits³ the impact of space upon health and life science innovation is already occurring.

With the UK building its space launch capacity, growing the launch provider ecosystem as well as its continued commitment of investment in the European Space Agency, the opportunity to utilise space infrastructure (including low earth orbit) and technology is set to grow.

In order to capitalise on this R&D opportunity and the growing commercial ecosystem (including tourism), it requires an understanding of how access to this unique environment can facilitate programmes of excellent basic science, as well as support government ambitions in developing the UK's world leading research and innovation system and global collaborations.

Alignment to existing UK Research & Innovation Strategy

One of the last UK strategy documents pertaining to UK involvement in life and biomedical sciences related to human space flight was released in July 2015, titled "National strategy: space environments and human spaceflight". Much has changed in the UK and internationally since that document was released, along with the recent developments of several strands of relevant activity including:-

1. UK Research and Development Roadmap
2. The upcoming UK Space Strategy & Defense Space
3. Consultation on spaceport and spaceflight activities including commercial spaceflight⁴

Now is the ideal time to revisit this topic. UK participation in ESA's SciSpace, UK Space Agency agreements with regard to the Artemis programme, ESA human spaceflight activities and LaunchUK ambitions for UK spaceplanes by 2040 all indicate multiple areas in which the UK could play a leading role with regard to health and life sciences research, skills expertise and innovation.

This requires a fresh review of this area in the UK to map an ambitious and connected strategy for how these sectors could inform and enable UK Government and industry to achieve their priorities with regard to commercial markets and international human space exploration endeavours along with benefits to terrestrial healthcare and life sciences which connect to the existing places of innovation excellence in the UK.

Reflections on the UK Government Research and Development (R&D) Roadmap⁵

Published on the 1st of July 2020 this policy paper sets out the UK government's vision and ambition for science, research and innovation and starts the conversation on how the UK can build on its R&D strengths and work to increase UK investment in R&D to 2.4% of GDP by 2027. By working to increase the interplay between the UK's leading strengths in Health and Life Science Sector and the Space Sector this roadmap aligns by:-

- Supporting the development, demonstration and deployment of new technologies and solutions towards commercial success or practical application

- Acknowledging that all academic disciplines contribute to the vigour of the research endeavour and asking how we can remove barriers to interdisciplinary research
- Diversify the way discovery research is funded to enable researchers to embrace the cutting-edge techniques and approaches, this could look at low earth orbit access
- Delivering 'moonshot' ambitions which can inspire both further research and the public. This aligns with the development of high-risk, high reward infrastructures with the creation of the Advanced Research & Invention Agency (ARIA)

ESA: Roadmaps for Future Research

Following consultations in 2016, the European Space Agency published its strategic goals to shape the future research programme of the agency. Comprising ten roadmaps in total, topics include Cosmic radiation risks for human exploration to astrobiology. Teams of international researchers (including from the UK) played a fundamental role shaping these key strategic requirements. With this exercise being refreshed in 2020 and due for publication in 2021, it will be important to use these roadmaps to support national and international collaborations that could fuel space exploration related R&D, as well as to elucidate the potential for translational terrestrial research. In the following sections, the opportunity for accessing the space environment including low earth orbit is discussed with case examples from existing and future operations.

"For some years now it has been recognised that distinct and significant synergistic benefit can be accrued from a strong relationship between the fields of terrestrial healthcare and space life and biomedical sciences. This paper highlights and provides valuable evidence of this fact, and indeed acts as a signpost for directions the UK is ideally suited to travel, and which could provide broad societal benefit if pursued."

Simon Evetts
Blue Abyss R&D Director
Visiting Professor Northumbria University
Co-founder UK Space LABS



¹ Erica Argueta C|NET: Space medicine isn't just for astronauts. It's for all of us
<https://www.cnet.com/features/space-medicine-isnt-just-for-astronauts-its-for-all-of-us/>

² Press Release UK Space Agency 8th April 2019:
<https://www.gov.uk/government/news/stargazing-technology-used-to-spot-cancer>

³ Press Release UK Space Agency 10th July 2020:
<https://www.gov.uk/government/news/space-agency-backs-space-enabled-drones-to-deliver-covid-19-testing-kits>

⁴ Spaceport and spaceflight activities: regulations and guidance -
<https://www.gov.uk/government/consultations/spaceport-and-spaceflight-activities-regulations-and-guidance>

⁵ UK Government R&D Roadmap 1st July 2020 -
<https://www.gov.uk/government/publications/uk-research-and-development-roadmap/uk-research-and-development-roadmap>

⁶ Roadmaps for Future Research – European Space Agency
http://esamultimedia.esa.int/docs/HRE/SciSpacE_Roadmaps.pdf

Access to the Space environment and Low Earth Orbit: What are the opportunities

For many years, Health and Life Science researchers have been utilising platforms both in orbit and on Earth to conduct fundamental research. The ESA Erasmus archives alone list >4000 funded and/or co-founded experiments, with nearly 600 of these just in the field of Human physiology ⁷ with examples including investigating how plants adapt in microgravity ⁸ providing valuable insights to support future exploration activities. Analogue environments (such as Concordia in Antarctica and HI-SEAS in Hawaii) and platforms (such as bed-rest studies, centrifuges and Clinostats/3D Clinostats) have also been developed on Earth to help researchers understand environmental effects and in some instances develop countermeasures to support human exploration activities. These opportunities have been utilised by both established research groups in the UK, as well as students through dedicated education initiatives (such as Spin, Drop, Orbit and Fly your Thesis from the European Space Agency, where UK based teams can also receive additional support from the UK Space Agency). With the increase in flight opportunities through the development of new commercial launch and service providers, previous barriers around access will be less prohibitive enabling more research groups to expand fundamental and discovery research and through appropriate funding and support, grow innovation opportunities with the Space sector.

Intrinsically tied to fundamental and discovery research, there are a number of mechanisms, both in operation and being established to support commercial exploitation of the Space Sector. For example the UK for over 10 years has hosted (through the Science & Technology Facilities Council, part of UK Research and Innovation) dedicated funded structures from ESA to facilitate space-related business incubation; ESA BIC UK ⁹, which has supported ~100 businesses including a number of cross-sector enterprises such as Entocycle and Crover. Downstream utilisation of space assets, for example satellite positioning and earth observation continue to see strong commercial development. Government funded infrastructures including the Catapult network (in particular the [Satellite Application Catapult](#)) and the [Knowledge Transfer Network](#) are already actively supporting the commercial development opportunity for space, working across multiple sectorial areas from in-orbit manufacturing and energy to health and life science. In 2020 the UK Space Agency supported the further development of space clusters across the entire UK building on the strength of the proven cluster model in stimulating intra and cross-sector activity, including between the Space Sector and the Health & Life Science Sectors for industry ¹⁰. With future ambitions from the European Space Agency to grow a sustainable low earth orbit and future lunar economy through its plans for a Business in Space Growth Network (BSGN) ¹¹ and the UK's drive to grow a diverse and ambitious space economy, there is an opportunity working with these existing infrastructures to further augment cross-sector connection and collaboration through supporting fundamental and translational research programmes, thereby creating a sustainable pipeline for our growing provider and launch ecosystem.

With an increasing number of potential launch providers, including Virgin Orbit, Skyrama, SpaceX, Blue Origin, Swedish Space Consortium, Orbex and microgravity platform providers including Airbus (Bartolomeo), Kayser Space, B2Space and Ice Cubes, there are more opportunities for health and life science researchers in the UK to utilise these growing space based platforms as well as Terrestrial analogues to conduct experiments. Below are two viewpoints from current and future providers.

⁷ ESA ERASMUS Archive
<https://eea.spaceflight.esa.int/portal/>

⁸ A decade of Plant Biology in Space
https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Research/A_decade_of_plant_biology_in_space

⁹ ESA Business Incubation Centre UK
<https://stfc.ukri.org/innovation/our-facilities-and-services/european-space-agency-business-incubation-centre-uk/>

¹⁰ UKR-STFC Proof of Concept Programme -
<https://www.harwellcampus.com/news/harwell-campus-proof-of-concept-programme/>

¹¹ ESA Business in Space Growth Network -
https://www.esa.int/About_Us/Business_with_ESA/Business_Opportunities/Commercial_Opportunities_for_Space_Exploration

COMMERCIAL SERVICES – FAST-TRACK ACCESS TO MICROGRAVITY

Dr Ramón Nartallo, Kayser Space Ltd.

Overview

Gaining access to microgravity facilities to perform experiments relevant to Biology, Medicine, Biochemistry, etc., is key to understanding the phenomena behind observed effects. This has traditionally required competing for space agency funding and flight opportunities; those successful, often waiting years for custom hardware to be designed, manufactured, space qualified and flown into space. Through the Bioreactor Express commercial service, Kayser is able to fast-track the development of customer experimental hardware and its deployment in the International Space Station (ISS). Working in collaboration with ESA, Bioreactor Express uses scheduled ISS-bound launches and provides exclusive access to the KUBIK incubator.

Building on experimental hardware developed by Kayser for the successful ESA BIOROCK mission, the Bioreactor Express service was kicked-off with the BioAsteroid mission, a University of Edinburgh funded bio-mining experiment completed within a calendar year, that flew to the ISS with SpaceX-21 in December 2020. The automatic culturing devices were incubated in the KUBIK ISS facility for three weeks, allowing bacteria to grow on a substrate of biocompatible meteoritic material. The capsule splashed down in the Atlantic Ocean on January 14th 2021. At least two other commercially funded experiments are scheduled with Bioreactor Express in upcoming SpaceX flights to the ISS.

Opportunity

Through the current government investment in space ports, and the existing industry-leading manufacturers of small satellites and launch systems, the UK is uniquely placed to lead the commercialisation of access to space. With its own UK base, Kayser specialises in the development of bio-incubators for space applications: hand sized laboratories equipped with electronics and mechanical parts that execute experimental protocols automatically, allowing for the growth, treatment and fixation of biological specimens cultured in microgravity. For us to be able to run a viable commercial service, the provision of life science experimental hardware needs to become more agile, standardised and much cheaper and quicker to implement. A market analysis and business plan based on actual demand for experiments on the ISS, shows that a viable commercial service such as Bioreactor Express will start to turn a profit within three years of operations. This is after taking into account the necessary initial investment in hardware devices and containers, that could be easily adapted to different life science experiments and flown multiple times. This approach removes the large costs and long lead times associated with hardware design, manufacture and qualification, thus making access to the microgravity environment affordable and fast.

Following this approach, Kayser is currently working with The Institute of Cancer Research and Imperial College London on the definition of three separate cancer research related experiments, where microgravity can provide a significant advantage. In all three cases, we are looking to define experiments that can be technically implemented by exploiting and/or adapting existing bioincubator technologies.



Image Courtesy of Kayser Space: Astronaut Michael Scott Hopkins performs the insertion of the BioAsteroid experiment containers in KUBIK. Credits: ESA/NASA

Going forward, Kayser, in collaboration with several leading UK universities, is embarking on a programme to develop sensors for bioreactors that would enable a range of in-situ analysis and monitoring activities of live samples, thus removing the requirement for samples to be brought back to Earth. These advances would enable the deployment of fully autonomous bioreactor systems on other platforms (e.g. cubesats) and environments (such as the lunar surface or Mars) where sample return is not feasible.

Looking further ahead, Kayser has been selected by ESA as a “sub-aggregator” of commercial payloads for the Space Rider platform and there are similar commercial prospects for the future space Gateway. The KUBIK facility itself could be adapted to other Low Earth Orbit platforms that are under development to exploit the post-ISS era, such as Dreamchaser or the Dragon Orbital Capsule. The Bioreactor Express service itself will be extended through the development of experiment hardware with built-in sensors for deployment in external space platforms and free-flying cubesats.

Dedicated Return: The Opportunity for Health and Life Sciences Off-ISS

Joshua Western, CEO, Space Forge

Overview

The benefits of conducting health and life science experiments in space have long been observed. The combined vacuum and microgravity environment, which cannot be replicated on Earth, have ensured space remains an environment where pharmaceutical, virological and pathological discoveries, treatments and potential cures can be accelerated. Since the inauguration of the International Space Station, the opportunities to access the space environment have grown immensely. From ESA experiments in nanoparticles to replace traditional antioxidants to commercial R&D from pharmaceutical companies such as Merck seeking to improve cancer drug delivery.

The ability to access the ISS for life science experiments can come in many forms - though national and commercial space entities. To a greater or lesser extent, all these platforms:

- Use shared infrastructure which can be subject to political interests

- Balance competing and often conflicting payload requirements
- Take up to 5 years for experiment approval
- Have long lead times to experiment commencement
- Have issues with achievable cleanliness and disruptions to microgravity from frequent maneuvers and dockings
- Offer limited ability for experiment return and the few vehicles that can return have hard landings

Space Forge is developing a platform for health and life science experimentation to overcome these barriers.

Opportunity

Low cost access to space, and the relative ease in which the environment can be exploited through the ISS and small satellites have fueled a new era of the space economy coupled with innovation. However, the missing lynchpin of a sustainable in-space ecosystem for research and development, is return. The opportunities to return from space are few and far between. They primarily rely on coming back from the ISS with solutions such as Dragon or Soyuz. ISS Capsules like Dragon only come back between 4-6 times a year, are difficult to access for commercial entities or small research platforms (astronaut constraints, national experiments etc.) and return at a highly accelerated G-load ending in a high shock impact as they land on Earth. A return solution which can offer gentle de-orbit and touchdown, coupled with extended stays in space off-ISS to access a superior space environment would unlock new H&LS applications and R&D opportunities.

Space Forge is developing the ForgeStar suite of platforms. These platforms are deployed on a conventional launch to a minimum orbit of 500km for dedicated experimentation and R&D for individual customers. Our platform is designed to stay in space for any time ranging from 10 days to 6 months, when a precision commanded return is initiated. The ForgeStar suite will offer payload capacity from 3kg to 75kg. The ForgeStar can overcome the barriers and issues associated with accessing the ISS:

- Offer a dedicated platform for H&LS dedicated to a single user.
- Be compliant with BSL2+ research.
- Return on demand, preserving experiment integrity.
- Compatible with a range of applications such as fluid dynamics, protein crystallisation and lunar/planetary gravity simulation.
- Offer regular flight opportunities throughout the year.

Space Forge is transforming how health and life sciences can leverage the space environment for research and development. Our flight opportunities commence in 2022.

In the following section this paper will discuss the opportunity as observed from a cross-section of the Health and Life Science and Space Community.

What is the opportunity for Health and Life Sciences Innovation?

There is significant opportunity for space health and life sciences innovation in the UK. This is illustrated by both the breadth and depth of existing expertise across a range of disciplinary areas captured in each of the following thematic chapters. Each of the chapters was informed by a rigorous scoping and data capture exercise.

Method

At the onset of paper development, two space health and life science community workshops were held at the Harwell Science and Innovation Campus in 2018 and March 2020. These workshops were attended by government, industry, clinical and academic stakeholders, offering an insight into current space biomedical R&D in the UK and outputs translatable to terrestrial needs.

Following the workshops, surveys and one-on-one interviews were conducted to understand existing capability in more detail, gather wider thoughts and inputs with regard to driving innovation, and to develop the community network within the different space health and life science sectors.

Subsequent to these activities, and based on the feedback we received from the community, a skeleton position paper was proposed and distributed in the summer of 2020. At that point, the community was invited to contribute structured abstracts detailing expertise and capability, applied case experiences of prior or planned work related to space, and recommendations for enabling this work. After an initial peer-review activity by the paper authors and steering board, a second call for abstracts was launched at the UK Space LABS workshop in November 2020. At this point, additional experts were contacted to secure input if they had not already contributed.

In total, we received over 50 contributions covering a range of topics. This included contributions from academia (N = 43), clinical (N=4) industry (N = 6) and public sector (N = 1).

After a further review and author revisions, a synthesis activity was conducted and abstracts assigned to the following thematic areas:

- Life Science
- Human Factors, Psychology & Neuroscience
- Bio-Medical and clinical considerations
- Engineering, Robotics, Data and AI
- Education and Knowledge Exchange

Each thematic chapter collated the inputs and themes from the contributions received. While many contributions can cross multiple themes, for clarity they have been mentioned in the most aligned thematic chapter and readers are encouraged to read the full list of contributors on page 44. We would like to thank and acknowledge each of the contributors for their expert insights.

Thematic Chapter: Life Science

Edited by: Dr Philip Carvil - & Professor Kate Robson-Brown - University of Bristol, UK

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Overview

Over the past few decades, a considerable number of life science experiments have been undertaken with the space sector. This research has ranged from fundamental research to commercial applications. The opportunity for the life science sector to utilise the unique microgravity as well as the radiation environment in space to undertake R&D continues to grow, with current and future launch providers (e.g. Virgin Orbit, Lockheed Martin, SpaceForge) and integrated service operators (e.g. Kayser Space, Ice Cubes, SpacePharma) increasing the capacity and availability for payloads. Coupled with the greater availability for life science experiments vs. those using human trials to utilise facilities and equipment on Earth to simulate these conditions (e.g. Drop Towers, Centrifuges, Clinostats etc) there is a considerable opportunity for the UK to strengthen its existing utilisation and cross-sector activity with the space sector (and aligned facilities) to drive new research and innovation

in the life sciences.

UK Researchers have already actively participated in the strategic initiatives including the Roadmaps for Future research for the European Space Agency ¹², inputting into key considerations from supporting human habitation in hostile environments to understanding the impact of Gravity on biological processes, cells and organisms. The UK's upcoming first national payload to the International Space Station, the Molecular Muscle Experiment 2, also builds on numerous biological UK experiments, with researchers from the Universities of Exeter and Nottingham using the small worm *C. elegans*, to understand the molecular causes of negative health changes in space, and the efficacy of novel drug and genetic treatments. Researchers at the University of Edinburgh, working with Kayser Space, flew the first commercial science experiment (BioAsteroid) from the UK to the ISS, to study interactions of microbes with rocks under the BioReactor Express programme. These experiments led to the development of a new bioreactor that can be used to carry out cell growth experiments of any kind in space.

With increasing commitments from both global governments as well as private companies in the coming decades to colonise space and nearby bodies (e.g. Lunar and Mars), there is still critical fundamental R&D to be done. From developing sustainable medical resources and processes (including tissue repair, infection management and supporting drug developments), understanding and developing improved countermeasures for diverse radiation environments to investigate and grow a supportive and diverse ecosystem (from bacteria and microorganisms to plants) that can enable life to thrive outside of Earth. Investing in these activities can also spawn new developments and commercial applications on Earth. The utilisation of microgravity environments have already supported the understanding of how to improve processes for drug delivery of large biologics. This unique environment could support novel developments for global issues, from tackling the anti-microbial crisis, to advancing the fields of precision medicine and improving the resilience of species to live in hostile environments. With examples of the UK's globally leading life science expertise (some represented in this chapter) there is an opportunity to support the exploration of space to drive new research and innovation in areas of existing strength.

Case Experiences

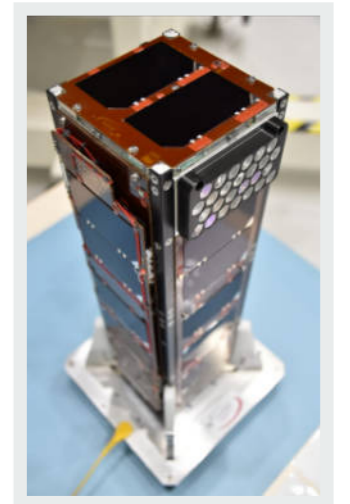
The UK has leading expertise and capabilities represented in a number of the contributed case experiences (some already mentioned), from radiobiology and tissue engineering to biotechnology and pharmaceutical research, including a number of active space life science research projects:

- Researchers at the University of Cambridge, together with colleagues at the Scottish Association for Marine Science and SCK CEN in Belgium are carrying out fundamental studies, funded by the ESA MELISSA POMP programme, on algal-bacterial communities and how these can be used to produce a source of vitamin B12, essential for crew health during long term space flight.
- In the field of Plant Biology, researchers at Imperial College London are currently developing 3D-printed, hydrogel-based, support systems to grow plant roots in soil-less and μg conditions. This is investigating how to control the development and branching of the root system even in absence of gravity with plans to collaborate with ESA or NASA to test the system on the ISS in μg .
- Researchers at the University of Southampton are looking at the potential use of (bacterio)phages as an alternative to antibiotics for treating space infections due to their high specificity and potential to help astronauts maintain a healthy microbiota on long-duration space travels.

¹² Roadmaps for Future Research – European Space Agency
http://esamultimedia.esa.int/docs/HRE/SciSpacE_Roadmaps.pdf

- In the field of Astrobiology, researchers at the University of Edinburgh have flown several space-related missions. For instance the ESA BioRock experiment was the first experiment to demonstrate the possibility of biological mining in space on the ISS.
- The company SpacePharma's UK-based operations have been leveraging its remote controlled miniaturised microgravity platforms, providing lab on chip testing environments in space to support experimental payloads including collaborating with Prof Lee Cronin at the University of Glasgow's group trialling the field of digital chemistry in space for the first time.
- In the field of Astropharmacy, researchers at the University of Nottingham have been funded by the UK Space Agency to investigate how medication management, research, policy and pharmacy practice could work in space and have also been working with NASA regarding regulatory and licensing issues for on-demand manufacturing particularly related to 3-d printed medication.
- In omics research, the UK already has significant expertise and infrastructure to assume a leadership role on Space Omics research, attracting both the funding to set up and co-found the European Space Agency's ESA topical team which has strong representation from UK Researchers, including at the University of Exeter, Nottingham, Cambridge, University College London, King's College London and Queen's University Belfast.

To support space exploration there are a number of translational capabilities from research active groups that could address future exploration needs, but also drive further fundamental R&D terrestrially.



- Over the years a number of tissue engineering projects have been conducted in space to look at cell behaviour and investigate the possibility of complex tissue manufacturing in space. At the University of Oxford, fundamental research into fabricated synthetic and living tissues (including neural) is being undertaken to support emerging medical therapies, which hold great potential to support sustainable human exploration. Researchers at the University of Manchester have been investigating how tissue engineering and bio-printing could be undertaken on Earth but also space environments.
- At the Centre for Antimicrobial Optimisation at Imperial College London, researchers aim to develop technologies which can optimise the management of infection, improve patient outcomes, and reduce the development of Antimicrobial resistance (AMR). This could support the development of rapid diagnostic solutions to tackle AME at point of care and clinical decision support systems which builds on previous work by UK research groups conducted in space investigating microbiome and infection treatment solutions.
- Researchers from the National Physical Laboratory have considerable experience in both the development of aligned facilities and investigating the effects of ionizing radiation (often used in clinical settings) on cells and tissues. These types of facilities have been used by international space agencies including NASA to elucidate the effects of space radiation on both human models and



Images above courtesy of SpacePharma of the DIDO-3 cubesat platform (above) and the SpacePharma Advanced Lab (SPAd) platform for the ISS
 Credit - SpacePharma

broader biological samples for risk modelling future space missions and understanding protective mechanisms.

Overcoming Challenges

Within the contributions there were a number of challenges highlighted, which could present opportunities for addressing.

Growing access and awareness of platforms: A number of groups highlighted that access to and research capacity to undertake R&D on the ISS has increased in recent years, but there is still a need to further develop the opportunities for flight models and platforms (such as parabolic flights) to increase capacity for science experiments, particularly when looking to have sight of pipeline opportunities from fundamental research to industrial application.

With the UK building its own launch capability this could become a key market area for the UK to leverage and support its world leading Life Science expertise to drive new R&D and industry partnerships and utilise this growing launch capacity. This would also facilitate focus on deep space platforms and aligned life science discovery.

Research Funding: A number of the groups also mentioned there was no dedicated funding, particularly in the proof of concept stage, for exploring the interface between these leading assets in life science and space, which is limiting the potential growth of these emerging areas (such as astropharmacy) and our future ability to cultivate long term international and commercial partnerships, particularly with launch providers.

The opportunity for funders to explore how through working with the space sector, this could stimulate interdisciplinary research collaborations would support cross-sector knowledge transfer, optimise terrestrial benefits and drive exploration research.

Dedicated Coordination: Given the excellent and diverse leading UK capabilities in Life Science (from omics and antimicrobial resistance, to tissue engineering and radiobiology) that have highlighted potential for further R&D utilising the space sector there is a need to develop infrastructure to support the coordinated engagement with these teams and the space sector. This would optimise outputs, support long term coordination and sight of pipeline opportunities which in turn would lead to potential novel methodologies being developed and supporting standards being developed to ensure R&D can be developed in a reproducible and scalable manner.

Skills: An opportunity (discussed further in the thematic chapter on education, page 36) was how through using space research applied to the life sciences this could inspire and stimulate the attraction into STEM careers and interdisciplinary learning.

Driving Research and innovation

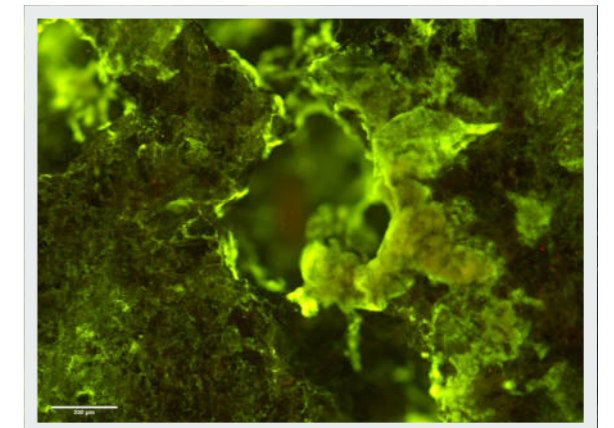
From changes in physical properties to alterations in certain processes, the unique space environment impacts across a wide variety of underpinning factors that could facilitate new understandings and developments in life science, that could support human space exploration as well hold the potential to revolutionise existing processes on Earth. Because of this breadth, contributors highlight the need for greater coordination, dedicated funding and facilitation mechanisms that can stimulate interdisciplinary collaborations. These collaborations could underpin global space exploration activities, while also supporting the terrestrial exploitation of discoveries to drive new commercial applications and innovation in key sectors of UK Strength, including in

precision medicine, radiation biology, agriculture, industrial bio production and pharmaceutical settings.

Working with commercial entities (such as large pharmaceutical players) also offers an opportunity for the research and innovation community to drive challenge led sponsored programmes and increase R&D investment. Through co-development with government organisations, from the UK Space Agency and national funders like UKRI and NIHR to regulators, there exists the opportunity to develop future innovation pipelines, while de-risking the UK's expansion of space exploration activities and continuing to increase and diversify future investment prospects.

"UK work in space life sciences allows us to contribute the exploration of space, but also to derive solutions to many Earth-based problems. For example, Microbes are pervasive in our industrial processes and health. By investigating them in space we are placing the UK at the forefront of space life sciences with its benefits to long term space exploration and for solving terrestrial life sciences challenges".

Professor Charles Cockell - University of Edinburgh



Images courtesy of Charles Cockell - University of Edinburgh

R: Image of the bioreactors being installed into the KUBIK centrifuges on ISS by Luca Parmitano - Credit: ESA

L: Image of Biofilm growing on rock for the BioRock experiment - Credit: Rosa Santomartino

Thematic Chapter: Human Factors, Psychology & Neuroscience

Edited by Dr Nathan Smith, University of Manchester, UK

This chapter is a synthesis of authored contributions from:

[Pg 52] - Diana Catherwood & Graham Edgar, University of Gloucestershire, UK

[Pg 115] - Elisa Ferre, Royal Holloway University, UK

[Pg 57] - Iya Whiteley, University College London, UK

[Pg 114] - Laurence Alison, University of Liverpool, UK & Neil Shortland, University of Massachusetts, USA

[Pg 66] - Maria Stokes, University of Southampton, UK

[Pg 120] - Marjan Colleti, University College London, UK

[Pg 81] - Nathan Smith, University of Manchester, UK

Overview

Human factors, psychology and neuroscience have an important role within the broader life and biomedical sciences. In the context of spaceflight, knowledge of and contributions from these areas can positively impact upon the safety, health and wellbeing, and performance of astronauts and cosmonauts as well as those working in operational roles such as in mission control. Research stemming from studies of human factors, psychology and neuroscience can potentially be applied at all phases of space operations, from habitat design, mission planning, assessment and selection of personnel, training, pre-mission readiness, in-mission monitoring and support, and post-mission recovery and rehabilitation.

There is already evidence of the important contributions to space life and biomedical sciences made by UK professionals working in the areas of human factors, psychology, and neuroscience. In the past, researchers at UK institutions have inputted on these topics during the development of human research roadmaps for the European Space Agency (e.g., Towards human exploration of space: a European strategy; THESEUS) and are currently involved in revisions and updates to new roadmaps focused on the application of such areas to lunar and deep space operations. These types of activities directly shape the science conducted by the international community in support of human spaceflight and demonstrate the expert capability that already exists in the UK.

Basic and applied research on these topics in relation to space has also been undertaken. For example, UK based researchers have examined fundamental questions relevant to spaceflight competencies (e.g., situational awareness and understanding), monitoring health and wellbeing of astronauts (e.g., voice analysis, temporal dynamics in mood during confinement, changes in

motivation over 6-month missions), supporting cognitive function, fine motor skill execution, and effective performance in space (e.g., Myotones project, vestibular neuroscience), and countermeasure development (e.g., Tools of Psychological Support during long duration missions). New research relevant to these topics continues to be conducted with UK involvement in the international SIRIUS missions through 2021-2023 (e.g., Stress, Health and Team Performance in SIRIUS; SHELTER), collaborations with the NASA Human Behaviour and Performance Laboratory (e.g., validation of standard psychological health measures), ESA Advanced Concepts Team (e.g., building agent-based models of team dynamics for moon operations), and developing digital platforms and technologies to support the psychological and cognitive function of humans in space. Much of this work overlaps with the other disciplines discussed in this paper, in particular the areas related to medical practices and data science.

"Exploring our inner space empowers us to more confidently explore outer space. To reach beyond our Solar System and settle across it, we need to tap into our human potential, develop and extend our abilities and training methods: Starting from Birth. For independent-reliant living, we need to continue to learn from nature, take into consideration all our human knowledge - modern and ancient - with the emphasis on a holistic and integral approach to community living, health care and wellness, including physical, mental, emotional, functional, spiritual and social aspects."

Dr Iya Whiteley, Space Psychologist, Director, Centre for Space Medicine, UCL.



Longer-term, and in some cases more speculatively, UK researchers are starting to consider how to ensure the safety, health and wellbeing of non-agency funded astronauts, including children and commercial space travellers. To tackle these, and other challenges discussed in ESAs new SpaceSci roadmaps, work on human factors, psychology, and neuroscience is increasingly being conducted at the intersection with other disciplines including architecture and habitat design, biomechanics and physiology, spacesuit design, and advances in telemedicine and robotics. Given human spaceflight is a growing sector, it is encouraging that scientists are already conducting innovative research on these topics and that UK capability is being developed. The benefit of this foresight and developed expertise has recently been illustrated in response to the covid-19 pandemic, where knowledge from psychological studies of astronauts and other isolated and confined populations has been used to develop training and education material to support frontline healthcare workers and the wider population facing conditions of isolation and confinement during lockdown. This example nicely illustrates the value of supporting human factors, psychology, and neuroscience research for space, where in the future the primary focus might be on enabling human exploration of the universe, but also having clear parallel benefits for individuals and groups facing isolated, confined and extreme conditions on Earth: whether through choice or in response to significant global challenges such as might be encountered during a pandemic or future climate related events.

Case Experiences

- UK researchers contributed to the development of the original ESA SpaceSci Roadmaps prepared in 2016¹³ and to 2020 updates focused on lunar and Mars exploration missions

¹³ http://esamultimedia.esa.int/docs/HRE/SciSpacE_Roadmaps.pdf

- Since 2006, Dr Iya Whiteley (Space Psychologist, Director, Centre for Space Medicine, Mullard Space Science Laboratory, UCL) has led numerous studies related to space psychology and human spaceflight. This includes an ESA project related to psychological support during long duration space missions and the development of expert tools to support crew autonomous operations in deep space. More recently, the UCL research team has focused on voice and content analysis tools to detect fatigue during exploration class missions. This research has led to products used in other extreme contexts, such as mining, aviation, and medical operations.
- Researchers at the Royal Holloway University of London are currently conducting vestibular neuroscience projects supported by national and international bodies, including ESA and ELGRA. This includes research on the effects of altered gravity on the human brain and behaviour.
- In 2019, a collaborative group at the University of Manchester and Manchester Metropolitan University initiated a number of new human spaceflight studies with international partners including ESA and NASA. This includes research examining the biopsychosocial basis of stress resilience in isolated and confined teams, which draws upon prior ESA supported studies examining changes in psychosocial function during long term isolation at Concordia station in Antarctica and during 6-month missions on the International Space Station (ISS).
- Within the UK, several PhD projects related to human factors, psychology and neuroscience in space are underway or in the initial planning stages. These projects cover issues including crew selection, training and countermeasures and team dynamics. Continued investment in early career researchers supports the important continued development of expertise and UK-based capability in this area of space health and life sciences.

Overcoming challenges

Contributors to the paper highlighted a number of challenges they face when conducting research on these topics in the context of spaceflight.

- Despite expertise existing in the UK and regularly being sought out by ESA and other international agencies, funding to support UK researchers involvement in human spaceflight research is often very limited. There are a number of examples of where researchers have been successful in developing valuable international collaborations with ESA, NASA and others, and through competitive processes, securing access to unique platforms such as the ISS, but then failing to secure funding to support their work. This limits the sustainability of impactful collaboration and long term capability development in these areas, which require funding for staff involvement, to support early career researcher development and exploit findings.
- The mechanism(s) through which to generate terrestrial impact from research conducted in space or space-like settings is lacking. Whilst there are clear areas where space-based findings can be extrapolated and applied to ground-based contexts, the best route through which to effectively disseminate and/or exploit is not always clear. This has been obvious during the covid-19 pandemic, where products stemming from human spaceflight research conducted by scholars in the UK could have been readily used to support the health and wellbeing of healthcare workers (e.g., stress and fatigue monitoring). However, there was no central route for translating and exploiting such work.
- The prior challenge feeds into a further issue related to the legacy management of human factors, psychology and neuroscience studies conducted by UK scientists in collaboration with ESA and other international agencies. Although ESA and NASA have their own project databases, there should be a UK repository where scientists can see what work has been conducted in the past. This is important for continuity and strategic capability building. There should be a

responsible owner for this activity, which would ideally be coordinated through a central governing institute or centre. It is possible that UK Space has this information in some form but a complete (or near as possible) publicly accessible repository would be beneficial to the community.

- A number of contributors highlighted the importance of thinking about research to support future human spaceflight. Most of the present research activities on space human factors, psychology and neuroscience conducted in the UK focus on immediate priorities of international space agencies. However, with the growing commercial interest in space, a wider range of people are likely to travel into orbit, the moon and on deep space expeditions, and thus research will be needed to ensure they can fly safely and stay well during such missions. Up front investment is needed to enable speculative research and capability development in this area, which is likely to have reputational, economic and societal payback as commercial activities in space grow.

Driving research and innovation

Suggestions for resolving some of the aforementioned challenges and driving research and innovation principally focus on the development of UK space governance, infrastructure and access to funding and partnerships. These developments would support innovative space-related and Earth applicable research relevant to current major societal challenges such as how to develop low-impact sustainable habitats for human thriving, understanding the biopsychosocial basis of stress resilience and how to train and support such responses, cognitive reactions and the mental health impact of living in isolated, confined and extreme conditions, and optimising the resilience and function of teams, groups and societies. To drive this research and innovation requires support. This might include:

- Establishing new agreements and development of governance between Research Councils (or equivalents), UK Space, other government departments and industry to both finance and potentially exploit space-based human factors, psychology and neuroscience research would be beneficial. This would help researchers and practitioners better understand how to support their work and where their programmes might contribute to the UK science landscape and commercial sector.
- Establishing a multidisciplinary centre for space health, similar to the European Astronaut Centre (EAC), would be a key enabler for conducting human factors, psychology and neuroscience research as situated within the broader space life and biomedical sciences. This might operate in a similar way to which the Defence Science Technology Laboratory (Dstl) functions alongside the Ministry of Defence (MOD) acting in coordination with the UK Space Agency and collaboratively with other international and commercial partners.
- Similarly, a translational research institute, modelled on the Baylor College of Medicine and NASA supported Translation Research Institute for Space Health (TRISH), would be beneficial for stimulating high impact research that has both space and terrestrial benefit.
- Funding administered through the aforementioned centre or institute, or directly by Research Councils, would provide the resources for long term projects and capability development. This might be used to support PhD students and early career researchers, as well as act as a vehicle through which to exploit and translate human spaceflight research to relevant Earth-based audiences and settings. This should include opportunities to commercialise research.
- The above activities would contribute to a more vibrant integrated network of space researchers and those interested in the field.

- Ultimately, the right agreements, infrastructure, funding and partnerships would enable human factors, psychologists, and neuroscientists in the UK to build on existing expertise and eventually take on a recognised leading role within the space life and biomedical sciences sector. Through the contribution to human space exploration and terrestrial application this support would have a positive scientific, economic, and societal impact for the UK.

Testing and Training Manual Tasks in Astronauts (Phase 1 of interactive system)

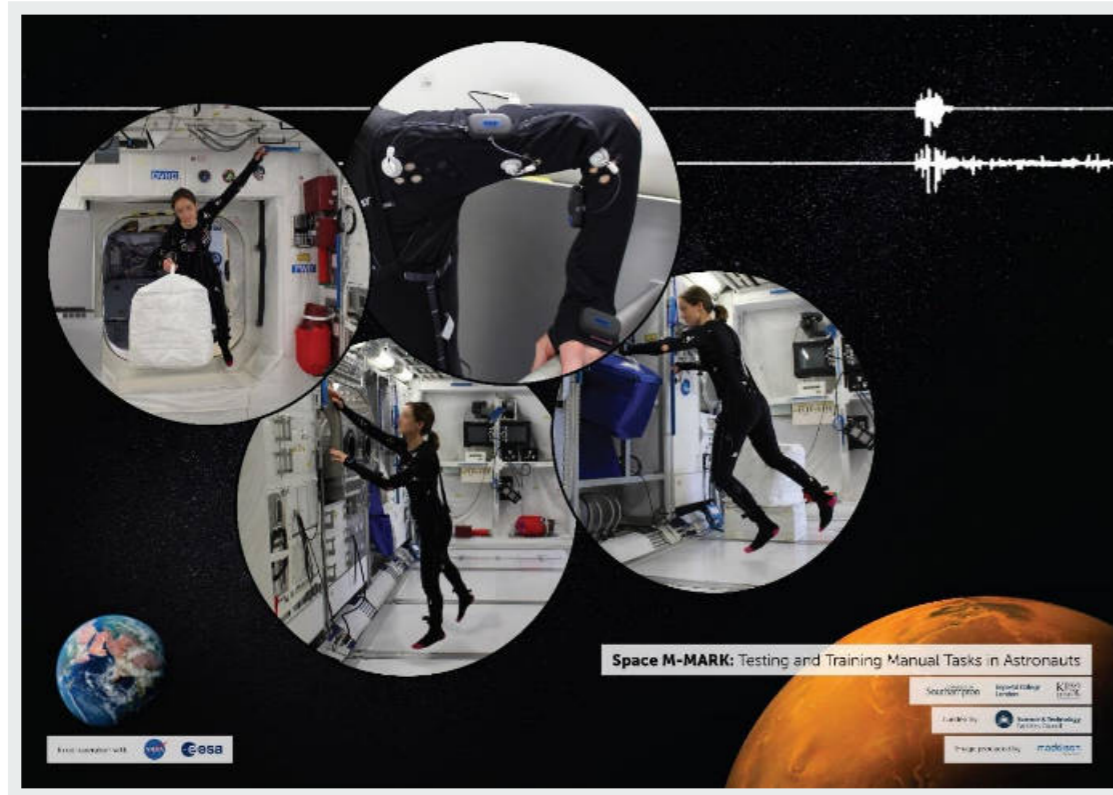


Image courtesy of Maria Stokes, University of Southampton

Undertaking Human space research, helps us understand how to best prepare and protect the human body from the extremes of the space environment. This has benefits not just for astronauts but also for populations on Earth. For example, for those with pre-existing conditions affecting muscles (e.g. Arthritis, neurological disorders) this research can inform rehabilitative processes. In the wider population, strategies to aid astronauts adhere to exercise programmes on long-duration missions will help guide uptake and maintenance strategies for the general population, to reduce risk of developing chronic diseases known to be associated with physical inactivity (e.g. cardiovascular conditions, Diabetes)"

Professor Maria Stokes – University of Southampton



Thematic Chapter: Bio-Medical and clinical considerations

Edited by Dr Peter D. Hodkinson - King's College London, UK & Dr Rochelle Velho, - University of Birmingham NHS Trust, UK

This chapter is a synthesis of authored contributions from:

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Overview

Space medicine is a diverse, multi-faceted field that is a key enabler of human spaceflight and operational capability. It exists to manage the human risk in spaceflight encompassing clinical, human performance and human factors engineering elements. On the clinical side this includes efforts to support crew health and wellbeing, to prevent ill-health in space, to risk assess potential medical issues and to integrate medical support capabilities into the vehicle or mission architecture from the start of the design process. In the event of medical issues arising, space medicine can provide in person medical support from medically trained astronauts or crew medics, telemedical consultations,

and medical equipment along with launch and landing cover.

As part of a holistic multidisciplinary approach to physical and mental wellbeing it also encompasses psychology, nutrition, exercise, and performance aspects. These all require research to advance the evidence base underpinning practice, to manage human risk in spaceflight and to support health and well-being on Earth and in space.

Along with elements already described within the life sciences thematic chapter, space medicine also presents a great opportunity for novel research to inform our understanding of physiology and disease processes of relevance to terrestrial or spaceflight populations. As discussed in the previous (second) chapter regarding human performance, space medicine specialists work with a multi-disciplinary team of physiologists, psychologists and human factors specialists. This is to bring together the diverse perspectives on potential physiological and performance effects of the spaceflight environment on individuals or teams that extends to safety cultures, operational environment and human behaviour. Space biomedical and clinical considerations also have implications for the design of protective equipment, systems or vehicles and habitats, which are discussed in the next (fourth) Chapter. Space physiology and medicine also represent an invaluable education and outreach tool that is discussed in the fifth thematic chapter. The current chapter will draw together and focus on examples across the spectrum of biomedicine and clinical considerations.

Case Experiences

Fostering the next generation of aviation and space medicine doctors through a space medicine training pathway:

- With a view to the future, the UK General Medical Council approved the new specialty of Aviation and Space Medicine in 2016. This is an important step forward and provides a path to training specialists in space medicine in the UK, but training places are limited to organisations willing to fund training.
- Currently this is the Royal Air Force and Civil Aviation Authority (CAA) where their focus is rightly on their main work requirements in the aviation domain. These organisations have begun working with King's College London, QinetiQ and other stakeholders to undertake research on suborbital spaceflight physiology that will inform development of CAA spaceflight regulations and guidance.

Translational applications from space medicine to improve musculoskeletal health in patients:

- There are significant challenges related to musculoskeletal health and disease in terrestrial and spaceflight populations; this is seen in changes related to ageing, sedentariness, back pain, muscular health and function.
- The UK has world leading expertise at multiple academic centres of excellence in the UK, who have experience in studying these effects to enhance understanding and provide healthcare benefit to terrestrial and spaceflight populations.
- Several institutions have designed innovative technological countermeasures and exercise interventions to minimise musculoskeletal deconditioning both in the laboratory and

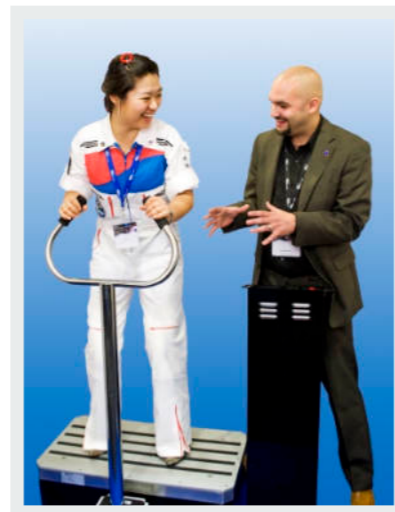


Image Courtesy of Adam Hawkey - Solent University Southampton.

spaceflight environments. This is exemplified by both the ESA SkinSuit research studies at King's College London and the Functional Re-adaptive Exercise Device developed by Northumbria University.

- Solent University Southampton are investigating the application of whole-body vibration training (WBVT - see Image opposite) and hand-held vibration training (HHVT) to improve health and athletic performance as well as the role of reduced gravity during rehabilitation of lower-limb injuries.
- The MicroAge project, scheduled for launch in November 2021, is a UKSA-funded national mission to the International Space Station (ISS) performed by the University of Liverpool in partnership with Kayser Space Ltd. The study will assess muscle adaptations to contractile activity occurring in tissue-engineered skeletal muscle constructs exposed to microgravity on the ISS.
- In collaboration with ESA and the German Aerospace Centre, the University of Liverpool are exploiting the state-of-the-art FLUMIAS microscope on board the ISS to examine the role of mitochondrial hydrogen peroxide (H₂O₂) as a mediator of rapid muscle loss under microgravity.

Translational applications from space medicine to cancer biology

- Cancer cachexia is the syndrome of muscle wasting and nutritional depletion experienced by cancer patients. Cachexia reduces patient treatment response, worsens physical function, reduces quality of life, and ultimately results in shortened survival. It is estimated to directly cause up to 50% of all cancer-related deaths and is therefore an enormous healthcare burden internationally. Astronauts, and terrestrial bed rest analogue studies, represent unique opportunities to investigate muscle wasting in humans (biochemically, physiologically and functionally). Further insights into the mechanisms and negative functional consequences of muscle wasting would help develop treatments for both astronauts and patients with cachexia, with important beneficial functional impacts for both groups (e.g. safety, mission effectiveness, and task completion for astronauts, and independence, quality of life and survival for patients).

Telemedical applications during the Covid-19 pandemic were developed to enhance human space exploration

- The UK is at the forefront of international efforts to drive forward miniaturisation and capability within robotic surgery. This can be done both remotely and at the bedside.
- This initial work on telemedicine that began in the space medical sector, has been growing exponentially within the UK and have been invaluable during the COVID-19 pandemic.

Space travel can be utilised as a tool for drug discovery

- Work by UK based scientists throughout the UK network of astronomy societies has contributed publications which advance scientific understanding of the application of the drug discovery and development processes to tackle problems associated with long term space travel.

Space health as a driver for research and innovation

- Members of the Royal Astronomical Society's Policy Group have contributed to the development of the UK Research and Development Roadmap which includes input for Future frameworks for international collaboration on research and innovation and the establishment of the UK Advanced Research and Invention Agency (ARIA).

Overcoming challenges

- The primary challenge is the absence of an accessible funding framework to enable space medical and life science professionals to conduct human spaceflight related research. At present, there is limited infrastructure and a lack of funding to support UK clinicians and biomedical researchers in this area. There is no broader overarching research strategy or bodies to guide space medical and life sciences research in the UK.
- These constraints limit the potential innovation and benefits this sector could deliver for terrestrial healthcare or science from such work or the important role UK personnel could play in supporting and contributing to human spaceflight and exploration. For example, some UK researchers on collaborative ESA funded projects are only able to secure funding for limited duration of the projects, while their European collaborators received full ESA funding.
- Another challenge is the lack of funding and opportunities to train in space medicine in the UK. The UK does not have its own human spaceflight programme and unlike French, German and Italian equivalents the UK Space Agency does not employ doctors or send them to support the European Astronaut Corps at the European Astronaut Centre.
- This could be addressed through UK Space Agency funding to train and grow a cadre of space medicine doctors with secondments to ESA or NASA to gain operational clinical experience. These would then generate and develop capability for the UKSA across the breadth of the speciality across clinical, advisory, research and innovation roles.
- Similarly, another challenge has been the lack of support for UK surgeons to apply their abilities or research in the context of spaceflight. If fostered, this could serve as a driver for technology innovation to support surgery in space but with clear potential innovation and benefit for terrestrial surgery. The UK has been slow to start on exploring the technical aspect of surgery within the microgravity environment or the wider reaching impact it can have. Data on the effects of wound healing, infection control or anaesthesia support remain limited.
- The UK Civil Aviation Authority also needs human spaceflight related research to address gaps in the evidence base underlying its development of regulations for future human spaceflight from the UK. This needs to be evaluated along with associated flight safety, governance and assurance considerations for these operations. The funding pathways and opportunities for such research are unclear and this area would benefit from better access to research funding.
- There is progress in pre-hospital patient monitoring, for example in a transportable setting, and syncing with hospital specialists during transit but again funding opportunities are limited, which constrain potential innovation in this area. There is also limited opportunity to apply any expertise in this field to the space context due to a lack of collaboration between the NHS, UKSA and international space agencies. This may be addressed by fostering these relationships, which would facilitate skill and knowledge transfer between health and space sectors as we are likely to see in the recently announced NHS, UKSA and ESA future 'space age' hospitals project.¹⁴
- There is limited contact between the UK and internationally based-astronautical hygienists. This has resulted in a lack of promotion of the discipline within the space medical and life sciences. If the infrastructure of astronautic hygiene is to be improved, then there is a need for partnerships between the biomedicine and engineering disciplines including training and education.

¹⁴ Announced 1st April 2021

<https://www.gov.uk/government/news/uk-space-agency-launches-multi-million-pound-drive-to-design-hospital-of-the-future>

Driving research and innovation

Inspiration, innovation, science, research and development are at the heart of space medicine practice. However, the UK space biomedical and clinical sciences sector needs research infrastructure and funding to support the potential benefits it offers. There are clear themes that can be seen across abstracts in this and other chapters. They demonstrate potential for terrestrial health and broader societal benefits along with provision of support to human health and performance in spaceflight. There is potential for space biomedical and clinical work to drive forward research related to terrestrial health challenges. These range from disease understanding, medical countermeasures or surgical systems, telemedicine and remote assessment tools that are of benefit to spaceflight and terrestrial populations. Additional research and innovation benefits include:

- The UK government's industrial strategy has set out 'healthy ageing' as a Grand Challenge, highlighting the importance of harnessing the power of research and innovation to meet the needs of our older population whilst achieving 5 more years of healthy ageing by 2035. Microgravity environments and analogues are an important resource for ageing research, providing a platform to examine accelerated ageing phenotypes in skeletal muscle and other major organs. Such research activities have clear terrestrial benefit, extending from fundamental mechanistic studies, through to the identification of druggable targets. Such work will also contribute to alleviating the use of animals in basic laboratory research.
- Advances in the generation of human models of muscle wasting (e.g. study of astronauts or bed rest volunteers) would provide valuable insights into the mechanisms and treatments of muscle wasting (for spaceflight or cancer patients) that are not easily available in the UK. Such a strategy would sit well alongside capacity-building research structures in the UK, such as the NIHR Cancer and Nutrition Collaboration.
- Spaceflight is a novel means of research but also a hook and driver of behaviour change in relation to exercise that brings a variety of health benefits such as reduced cardiovascular risk and through musculoskeletal conditioning to support functions of daily living and quality of life aspects of healthy ageing.
- The importance of physical activity on both our physical and mental health has been heightened due to recent events surrounding COVID-19. In addition, physical activity is now regularly used to improve patients' fitness prior to surgery, and to help combat epidemics such as obesity and diabetes; all of which are helping us to live healthier lives, for longer. In the future, greater research collaboration and knowledge exchange activities between the UK human spaceflight and sports science and rehabilitation communities has potential to catalyse research and innovation in each of these areas.
- The rapid innovation and reduction in the size of mechanical ventilators evidenced during the COVID-19 pandemic demonstrated the possibility of rapid innovation and translation when the need arises and of course the networks, funding and commercialisation are all aligned. Innovation and technological advances may also extend to drug discovery and development or novel digital technology for patient monitoring in remote or pre-hospital settings.
- Equipment innovation to overcome challenges in microgravity, such as the need for a redesign of chest drains for pneumothorax or the development of automated image guided robotic percutaneous interventional systems could lead to terrestrial benefit as well. These would profoundly change the landscape of the need for surgical intervention in trauma. It is already evident that interventional radiology is a growing speciality and in terms of trauma can now manage 95% of traumatic splenic injuries when previously most patients would require major surgery.
- The instigation of robotic automated processes in pharmacy or other areas and also

incorporating AI and machine learning tools to enable predictive analytics associated with astronaut diagnostics and clinical investigations performed during missions.

- Promoting accelerated training for surgical trainees through digital coaching.
- In a holistic systems engineering approach to new vehicles, habitats or other systems for space, a work strand on human factors engineering to advocate for human-centred design should be integrated into the early phase of the projects. This should be a multidisciplinary approach to consider the great diversity of elements that need to accommodate human needs for survival, function, performance and wellbeing.
- A collaboration of Universities led by UCL and UK Analogue Mission are developing a pilot analogue mission that will investigate interdisciplinary space health within the context of a simulated exploration of another planetary body. This will be the first empirical study in the UK that investigates interdisciplinary space health practice and provides the foundation of future UK space analog missions that provide valuable opportunities to field test systems and procedures for spaceflight.
- From a space-flight perspective, the Artemis programme is ushering in a new era of space exploration as humanity pushes boundaries, building a long-term presence on the moon by the end of the decade. The Artemis missions will build the foundations for supporting and sustaining life away from earth, as such it is important for us to understand the biological implications of such endeavours so that we may develop effective intervention strategies to preserve astronaut health under microgravity.
- The potential for human enhancement for risk mitigation strategies in long duration spaceflight that may have terrestrial applications.

In summary, space medicine, as part of a broad multidisciplinary approach, is a key enabler and essential element for any human spaceflight programme. Operating at the intersection of science, technology and engineering; space biomedicine and clinical considerations play a critical role in supporting health and wellbeing in space and terrestrial benefit for all along with contribution to research, innovation and development of future operational capability for human spaceflight.

However, as described in the previous chapter there is currently no centre for these capabilities to be developed and the establishment of such a centre would bring great benefit to the potential this sector offers to UK research and development. This would provide a vehicle to nurture closer collaborations between the NHS and the UK Space Agency, via an infrastructure framework implemented to support UK-based NHS Healthcare staff and scientists to conduct research with international space agencies and relevant commercial partners. By creating a hub for communication and outreach to the general public on the application to problem solving of UK based technology and expertise in space biomedicine and health would also harness the great potential for space harboured research to benefit humankind and capitalise on these



"Access to the microgravity environment presents an accelerated model of musculoskeletal deconditioning directly relevant to many healthcare populations on Earth, with the unique benefit of allowing researchers to study injury-related deconditioning from before the injury occurs."

Professor Nick Caplan, Northumbria University

areas of research and development.

Such a centre would provide the funding, training structure and partnership opportunities for established, early career, biomedical science and clinical researchers to engage in responsive, stakeholder-driven, innovative research and development of medical devices and other technology for human spaceflight and terrestrial benefit. A Centre or virtual 'space medical village' infrastructure would produce critical mass and enable capacity building with a career pathway for innovative young minds to flourish and become world-class space research leaders.

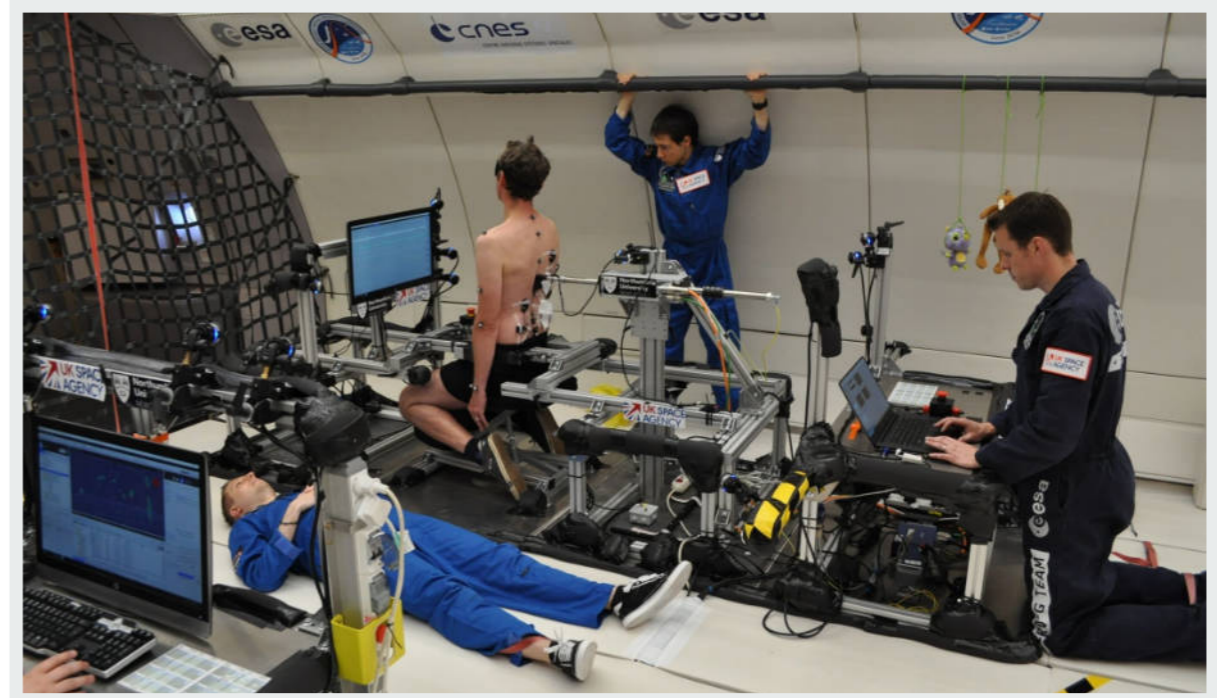


Image Courtesy of Nick Caplan - Northumbria University

The Northumbria University research team on the 1st Inter-agency parabolic flight campaign 2018 Credit: Northumbria University



"Investigating how biological systems respond and adapt to the challenging environment of space ultimately informs us more about how organisms, including humans, adapt on Earth. This aligns with current terrestrial grand challenges, such as those relating to the growing older population and the drive for more personalised medicine. This report brings together voices from across the health and life sciences sector and I welcome how it highlights the wide ranging benefits that space-related research can bring."

Professor Stephen Harridge, Centre for Human and Applied Physiological Sciences, King's College London

Thematic Chapter: Engineering, Robotics, data and AI

Edited by Professor Kate Robson-Brown - University of Bristol, UK

This chapter is a synthesis of authored contributions from:

[Pg. 78] - Ashfaq Gilkar - Guys and St Thomas' NHS Foundation Trust, UK

[Pg. 101] - Charlie Young, Chris Smith, Graham Schultz - Plastron UK, UK

[Pg. 106] - David C. Cullen and Aqeel Shamsul - Cranfield University, UK

[Pg. 49] - Gianluca Neri - Kayser Space Ltd.

[Pg. 71] - Harish Bhaskaran - University of Oxford, UK & Nina Vaydya - California Institute of Technology, USA

[Pg. 112] - Li Shen - Imperial College London, UK

[Pg. 70] - Matthew Dickinson - University of Central Lancashire, UK

[Pg. 64] - Patrick Magee - Magee Medical Systems

[Pg. 104] - Pedro Madrigal - University of Cambridge, UK

[Pg. 99] - Thais Russomano - King's College London, UK & InnovaSpace UK.

[Pg. 100] - William Abraham da Silveira - Queen's University Belfast, UK

Overview

The environment of space is hazardous to life, and all life support in space is dependent on technology. Generations of space engineers and scientists have dedicated their careers to supporting the health of astronauts and the viability of other living organisms through launch and return, in orbiting spacecraft and on experimental platforms. The current landscape of research and development in this sector is rich and diverse, and characterized by strong collaborative programmes linking academic research groups, industry and public organisations such as space agencies. These programmes have delivered many innovations in engineering, design, new materials, control systems, manufacturing and robotics, and the life and biological sciences continue to be a driver for ambitious next generation solutions to challenges both in space and on earth. Underpinning these innovations, data science and data-driven approaches have seen significant adoption, with many activities being initiated across space agencies, research centres and commercial organisations and initiatives. Digital and data technology is now woven through all aspects of engineering, across all sectors of research and development.

Space agencies across the globe are now focussing support on health, life, and biological science projects which harness the power of data science, and in particular over the last few years Artificial Intelligence (AI) and machine learning, simulation, cloud platforms, the Internet of Things (IoT), Big Data Analytics, and augmented and virtual reality (AR/VR) have received particular attention. These initiatives are a positive response to the opportunities presented by the flow of data from space sensors, life support, and experiment sensors, and they are increasingly driving the agenda of what has been dubbed 'Space 4.0' – like the often quoted Engineering 4.0 this vision refers to the opportunity presented by the integration of digital technologies to transform the space sector through improved efficiency and productivity. The UK has the expertise and capability to lead the development of next generation engineering, data science and AI innovations for health, life and biological sciences in space, and drive the translation to terrestrial benefit in the UK and beyond.

Case Experiences

In the contributions discussed there were a number of case areas highlighted including:-

- **Life support systems** – bioengineering development of human respiratory life support systems
- **Medical technology** – sensors, IoT, connectivity, predictive modeling
- **Assistive technology** – exoskeleton, wearable sensors, rehabilitation technology
- **Space science** - experimental platforms, experimental design, big data and multi-omics, miniaturized hardware platforms, fluid dynamics in microgravity
- **Innovative manufacturing** – 3D printing, automated design, patient specific modelling, in-orbit laboratory and service provision

Overcoming Challenges

The health, life and biological space sciences in the UK are well placed to lead the world in developing next generation discovery, applications and technology, and the challenges faced by the sector can be addressed.

- **Infrastructural fragmentation.** While engineering, data and digital innovation related to health, life and biological space science activity is ongoing across the spectrum of academic research departments in universities and public and commercial organisations, there are few mechanisms for sharing good practice, accessing funding for projects directly, or improving high level visibility within government and funding bodies. The sector would benefit from leadership, development of research strategy, and clarity of national priorities.
- **Data infrastructure development and Data Intelligence.** The UK could develop infrastructure to improve and facilitate data sharing, asset management, and data communication. This could include guidance on shared data/metadata standards.
- **Sector development** – The UK could address the skills development needs for the sector, improve access to funding and support development of the regulatory framework.
- **Mission engagement** – Many individuals and research groups in the UK are strong partners in missions initiated elsewhere, but the UK should lead and launch a national mission.
- **International Partnerships** – digital and data could be core capabilities for UK investment in

space, for example through the Artemis programme. The UK could contribute directly by developing robust mechanisms to underpin such partnerships, for example around IP and data sharing, or develop a strategic partnership with the new ESA Data Centre (ESAC, Madrid).

- **Global challenges** – Maximising benefit and value should not be limited to the UK; there could be a national priority to articulate the UK space digital and data sector's role in areas such as responding to climate change, disaster relief, tackling human trafficking, epidemics, and reducing space debris and enforcing space security for all.

Driving Research and Innovation

In the context of low earth orbit, health, life and biological science activities are generating ever larger and more complex datasets, much of which requires streaming for real time capture and analysis. Experimental hardware now often has a requirement to be driven remotely, or function autonomously. This will significantly increase in the coming years as researchers demand more real-time data from on-station analysis tools and remote control systems. At the same time, there is a need also to limit human engagement time and the contain the complexity of training requirements. This demand is driving the development of novel ecosystem of commercial LEO solutions, uncrewed, and offering a variety of mission deployment systems and flight durations, which could well bring down the cost of access and open up opportunities for the supply chain industries. All these systems, on the horizon, will need data infrastructures, data engineering solutions, software development and new analytics, and in many ways we are well placed in the UK to take advantage of these opportunities, given our existing wealth of expertise from related sectors.

All the technologies which are part of Industry 4.0, i.e. AI, Cloud, Big Data, IoT, are transforming the way health sensor data, biological experimental data and earth observation data is being processed, analyzed and used. This transformation does not necessarily mean using only siloed datasets to draw insights – but integrating different data sources to draw out analysis using AI and ML. From a European perspective, especially concerning the Copernicus program, new data platforms are being developed to receive, process and archive the massive volume of satellite data collected from the Sentinels and other contributing commissions. These data platforms are established on the cloud, and work with AI and machine learning enabling the development of new applications in the EO sector. Many have argued that this accelerating digital transformation in the space sector will bring with it new business models for the space industry, and benefit many aspects of terrestrial population health. Where large data sets are derived from medical sensors and biological experiment data, there is a drive to improve predictive modelling using AI and ML, and the development of subject specific digital twin systems.

In the context of lunar missions, the health, life and biological sciences are expected to play a leading role in driving technological innovations. The Artemis programme aims to take humans back to the moon and beyond, supported by sustainable lunar exploration, and this ambition will be achieved through partnerships between academic, commercial and international public organisations. The Human Landing System is in development, and the orbital Gateway station Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO) are planned for launch together in 2023. The commercial partnerships are core to this ambition – the lander is commercially developed. New spacesuits are in development that incorporate sophisticated comms and life support systems. On the Gateway, research will be conducted using novel experimental platforms and there is a strong drive towards interoperability of components and digital and data platforms. The Canadian Space Agency (CSA) has committed to providing advanced robotics for the Gateway, and ESA (European Space Agency) plans to provide the International Habitat (IHab) and the ESPRIT module, which will deliver additional communications capabilities, a science airlock for deploying science payloads and CubeSats, and refueling of the Gateway. The Japan Aerospace Exploration Agency (JAXA) plans to contribute habitation components and logistics resupply. At the lunar South Pole, NASA and partners

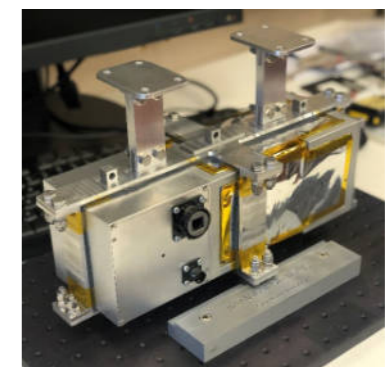
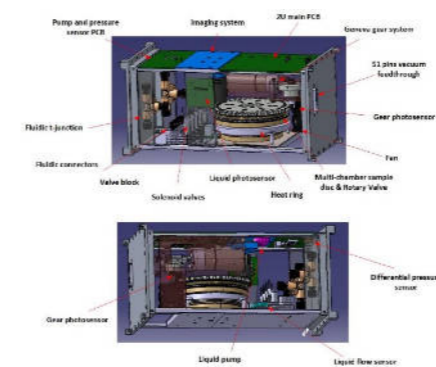
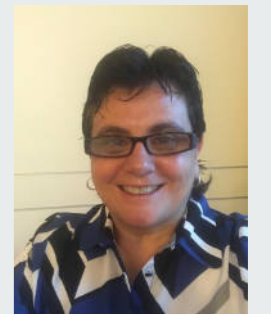
will develop an Artemis Base Camp to support longer expeditions on the lunar surface. Planned Base Camp elements include a lunar terrain vehicle (LTV, or unpressurized rover), a habitable mobility platform (pressurized rover), a lunar foundation habitation module, power systems, and in-situ resource utilization systems. This long-term gradual development of capabilities on and around the moon is seen as essential to establishing long term exploration capacity and preparation for human exploration of Mars. All components of this vision rely on sustainable engineering solutions, new technologies for life support, trustworthy, innovative digital and data-driven systems and processes including positioning systems, machine vision, and autonomous and remote operability.

Future visions of interplanetary travel and human presence on Mars and beyond will only be realised if the challenges to digital and data infrastructure are addressed as a priority. Here, the challenges to exploration are extreme because the constraints are significant in terms of deploying technology. There is currently a lack of communication infrastructure required for high throughput data flow and data based services such as GPS. Relying on more autonomous technology may be one way forward, and this ambition opens up opportunities to the AI, robotics, and computer vision research communities. For Mars orbital platforms in particular, the development of on-board analytics including ML solutions will be crucial to mission success.

Health, life and biological space science has long played a pivotal role in driving the direction and deployment of engineering, data and digital innovations, not only in the context of space but also translated to terrestrial benefit. The impact of research and development in this sector has been felt in many disparate fields including weather and space weather monitoring, climate change modelling and nowcasting, agritech and precision farming, public health monitoring, telemedicine, mental health interventions and human performance, robotic surgery, digital twins, new materials and manufacturing, interconnected medical technology and monitoring supporting precision medicine and person centred care, patient specific interventions, rehabilitation, and disaster relief.

"The space sector is as vast as the universe itself and one of the most interdisciplinary areas of R&D and collaboration. Whether creating enormous orbiting laboratories or experimental platforms for studying the adaptation of different life forms to the microgravity environment of space, interdisciplinarity is at its foundation, bringing with it translational benefits to collaborative research on Earth."

Professor Thais Russomano, Centre for Human and Applied Physiological Sciences, King's College London



Images Courtesy of David Cullen – Cranfield University

Left image – labelled CAD representation of the 2nd generation BAMMsat 2U payload design indicating various features.

Right image – photograph of the 2nd generation BAMMsat payload in preparation for flight on the BEXUS stratospheric balloon platform and with the addition of a 1U avionics module (on left end of payload) and a mounting bracket for interface to the balloon gondola frame

Thematic Chapter: Education & Knowledge Exchange

Edited by Associate Professor Adam Hawkey - Solent University Southampton, UK

This chapter is a synthesis of authored contributions from:

[Pg 87] - Nigel Savage - HE Space Operations for ESA - European Space Agency, The Netherlands

[Pg 111] - Daniel Molland, Zoe Gaffen, & Julie Keeble - Kings College London, UK and International Space School Educational Trust (ISSET)

[Pg 61] - Adam Hawkey - Solent University Southampton, UK

Overview

For centuries, space has been a source of inspiration to humanity. This continues to the present day and is responsible for the creation of new industries and the development of new career paths within already established areas. While scientific endeavour and research are fundamental to this progress, effective education, knowledge exchange and the delivery of outreach activities are also important to encourage and enthuse the next generation of scientists, engineers, teachers, healthcare professionals and astronauts. In 2016 a new medical speciality 'Aviation and Space Medicine'¹⁵, was recognised by the General Medical Council, and this has the potential to improve opportunities for those with a professional interest in the discipline. This interest is further evidenced by 53 of the 272 applicants (and six of the selected 52 candidates) for ESA's Space Physician Training Course (SPTC2021) being from the UK. Similarly, of the 150+ applications for ESA's Human Space Physiology Training Course (HSTC2020), 12 UK individuals were in the top 75 candidates; of the 12 eventually selected for the programme, seven were from the UK.

Several universities in the UK, including Imperial College London, King's College London, University College London, and Northumbria University, offer higher education courses (e.g. PGDip, MSc, and BSc), or modules, that incorporate space physiology and medicine into their syllabus¹. Many other academic institutions provide insights into human physiology in the extremes, with distinct references made to the space environment. There are some specific examples where aspects of space physiology/biomechanics have been utilised to benefit terrestrial applications, such as the use of reduced gravity technology in sports rehabilitation. University engagement in space-related topics can be further evidenced by the inclusion of a special expert panel, comprised of representatives from UK SpaceLABS and ESA, at the British Association of Sport and Exercise Sciences (BASES) 2021 Student Conference; in which the physical challenges of extended human spaceflight were highlighted¹⁶.

¹⁵ Centre for Altitude Space and Extreme Environment Medicine, University College London
<http://www.case-medicine.co.uk/Education>

¹⁶ UK SpaceLABS Expert Panel on Human Spaceflight.
<https://www.solent.ac.uk/solent-sport/bases-annual-student-conference>

Outreach activities, knowledge exchange, and public engagement have also been used to capture the public's imagination around space. While some of these events and media coverage have catered for the general population¹⁷, the majority have been tailored to a younger audience. One such example, a recent Royal Institution (RI) Christmas Lecture, delivered by Dr Kevin Fong, was focused on the topic of *How to Survive in Space*¹⁸. The RI was also used by The Physiological Society to 'launch' their educational animation: *What happens to your body in space? Mission to Mars*¹⁹. Aimed primarily at secondary school-aged students, the animation accompanied a series of online resources related to space physiology²⁰; both utilised scientific advisors from UK universities and former NASA astronaut James Pawelczyk. Capitalising on the exploits of Major Tim Peake's Principia Mission has also been a feature of space-related education and knowledge exchange. A prime example of this is the Tim Peake Primary Schools Project, designed to promote STEM engagement by providing resources that linked many aspects of the curriculum to his International Space Station (ISS) mission. This offered a range of opportunities to help children and teachers become more aware of space, and the opportunities this may hold in the future. Topics covered in this project included what astronauts eat in space, how to keep fit in microgravity, and the importance of maintaining bone health; both on and off the earth²¹.

Other STEM-related activities, like *Mission X: train like an astronaut*²², have been complemented by media coverage aimed at school children. These have included: Curious Kids articles highlighting the challenges of travelling to Mars in educational publications like *The Conversation*²³; news reports on the effects of space travel on the human body for the BBC's *Newsround* programme²⁴; and popular children's television shows like *Horrible Histories* showcasing what it would have been like for the Apollo astronauts during their lunar missions²⁵.

¹⁷ Hawkey, A. (2020). Do you have the right stuff to be an astronaut? *The Independent*. Available at: https://www.independent.co.uk/news/long_reads/science-and-technology/how-become-astronaut-spacex-elon-musk-nasa-iss-a9581121.html

¹⁸ Fong, K (2015) *How to Survive in Space*. Christmas Lecture, Royal Institution, London.
www.rigb.org/christmas-lectures/watch/2015/how-to-survive-in-space.

¹⁹ The Physiological Society *What happens to your body in space? Mission to Mars Educational Animation*
<https://www.youtube.com/watch?v=y7rDrAKRqjo>

²⁰ The Physiological Society "Space Physiology"
<https://www.physoc.org/careers/research/space-physiology/>

²¹ Tim Peake Primary School Project
<https://www.stem.org.uk/community/groups/155593/tim-peake-primary-project-20162017?page=9>
Tim Peake Primary School Project
<https://www.stem.org.uk/community/groups/155593/bone-density-and-effect-space-visit-dr-hawkey-lindfield-primary-academy>

²² Mission X: Train like an astronaut
<https://www.stem.org.uk/elibrary/resource/31444>

²³ Hawkey, A. (2020). Curious Kids: why can't we put people on Mars? *The Conversation*. Available at: <https://theconversation.com/curious-kids-why-cant-we-put-people-on-mars-130013>

²⁴ BBC - [What are the effects of space travel on the human body? - CBBC Newsround](https://www.bbc.com/news/health-5581121)

²⁵ Horrible Histories: Moon Mayhem
[https://www.bbc.co.uk/iplayer/episode/m0006w7j/horrible-histories-series-8-7-moon-mayhem?xtor=CS8-1000-\[Discovery_Cards\]-\[Multi_Site\]-\[SL08\]-\[IPS_IPLAYER-N--P_HorribleHistoriesS8E7\]](https://www.bbc.co.uk/iplayer/episode/m0006w7j/horrible-histories-series-8-7-moon-mayhem?xtor=CS8-1000-[Discovery_Cards]-[Multi_Site]-[SL08]-[IPS_IPLAYER-N--P_HorribleHistoriesS8E7])

"Education and knowledge exchange in the field of human spaceflight are unparalleled lightning rods to capture and simulate the interest and aspirations of young people not only in spaceflight, but across the STEM disciplines. Furthermore, given the historic lack of engagement in human spaceflight the high representation of the UK, and its young citizens in educational initiatives has been, and will continue to be key in building capacity to exploit and leverage the UK's participation in the ISS and exploration programmes, in addition to supporting and leading the growth of UK commercial enterprises."

Dr David A Green, - Visiting Senior Lecturer in Aerospace Physiology
King's College London, UK



Case Experiences

The European Space Agency (ESA) Education Programme was established to inspire and motivate young people to enhance their literacy and competence in science, technology, engineering and mathematics (STEM disciplines) and to pursue a career in these fields; in particular the space domain. The programme incorporates several exciting activities ranging from training and classroom activities that use space as a teaching and learning context for school teachers and pupils, to real space projects for university students. Enveloped within the ESA Academy, activities complement academia by providing a link between university education and professional experience. "Hands-On Programmes" cater for engineering students as well as scientists who want to gain access to space or altered gravity platforms. These programmes include "Fly a Rocket!", "Fly Your Satellite!", "Rexus/Bexus", "Orbit Your Thesis!", "Fly Your Thesis!", "Drop Your Thesis!", "Spin Your Thesis!" and "Spin Your Thesis! Human Edition". While the "Fly a Rocket!", "Fly Your Satellite!" and "Rexus/Bexus" programmes are geared toward engineering and non-life sciences, the other (Your Thesis!) programmes give teams access to life-science friendly platforms, which include the ISS, parabolic flights, large diameter and short-arm human centrifuges. Since 2015, 24 students with UK citizenship have been selected to participate in the Hands-On Programmes. These students formed part of seven teams spanning nine UK Universities. Of these seven teams, three performed life science experiments. Interestingly, all these used centrifuges, investigating the effects of hypergravity on the human skeleton, plasma membrane fluidity, and arthritis, respectively. One team, for example, the Bristol Bone Biologists from the University of Bristol, successfully applied for "Spin Your Thesis!" in 2018 and investigated how hypergravity affected developing zebrafish embryos.

Within the Centre for Human & Applied Physiological Sciences at King's College London, the Keeble research group offers a unique opportunity for undergraduates to develop experiments for launch to the ISS. The experiments that students develop cover a range of research disciplines from protein activity studies through to applied physiology on small organisms such as *Daphnia* or earth worms. By exposing undergraduate students to the challenges and rewards of developing experiments for spaceflight, this group acts to empower the young scientists who will be central to the UK's long-term ambitions in space. Directly supporting



Image courtesy of Nigel Savage
Credit: European Space Agency & Novespace

experiments developed within this group is the International Space School Educational Trust (ISSET), which provides educational experiences (e.g. the Mission Discovery programme) for students aged 14-18. The students are supported by a range of NASA astronauts and engineers, alongside university scientists. The winning ideas are fed into the Keeble group, which are then developed by undergraduate students into fully functional experiments. To date, this scheme has produced over 30 experiments, launching aboard eight separate commercial resupply missions. For both under- and post-graduate students, the development of these experiments provides an unparalleled educational opportunity, with students learning how to balance the constraints of performing an experiment in microgravity while maximising scientific benefit. By providing a feasible method of access for undergraduates to work with projects that are sent to space, the Keeble group equips students with the knowledge and technical expertise required to handle biological spaceflight experiments.

Overcoming Challenges

The UK's engagement with ESA's space physiology and space physician training programmes is encouraging. However, that aviation or space medicine are not included in UK medical school teaching curriculum requires reflection and potentially reform. Similarly, while several UK universities offer modules in extreme environment physiology, these are usually linked to a sport and exercise science programme, and therefore have a strong focus on the teaching of terrestrial-based physiology such as heat, cold and altitude acclimatisation rather than human spaceflight. It would, therefore, be desirable to better integrate provision and resources to allow for the more effective teaching of space physiology within a higher education setting.

Space life science-related education is evident in a variety of informal ways throughout the primary school age group (e.g. Tim Peak Primary Schools Project). Yet there is a noticeable, and concerning, absence in secondary curricula. Most of the teaching around space in a secondary school setting is focused on physics (e.g. gravity on other planets and stars) and while there is a requirement for basic 'biomechanics' (i.e. skeleton and musculature) there is no specific reference made to space life sciences, or health applications²⁶. There is little, or no, material specifically developed for schools that refers to the biological dimensions of spaceflight. Although the notion of space exploration is perceived as motivating, there may be a curricular disconnect between physics and biology that inhibits such teaching. *(The) Biologist* has featured articles on *Combating bone loss in space and Extraterrestrial Life Science*²⁷, but dedicated articles on the topic in journals such as *School Science Review* are rare.

Driving Research and Innovation

Space clearly has a valued place in the UK education sector. While it can be, and has been, used effectively as a vehicle for learning in relation to STEM, the inter-disciplinary and cross-curricular potential goes far beyond just these subjects. There does now need to be a clear and focused integration of space life sciences in the national curricula and beyond. It is imperative to develop educational and training initiatives to inspire and influence careers in the health and life sciences, especially given the importance of this sector through the recent COVID-19 pandemic. The space sector is in a unique position to help the health and life science sector by contributing to the development of outreach and education projects to raise the sectors profile, which could generate new interest in potential commercial and industry applications and in the establishing of new career pathways. Finally, increasing accessibility to life science experiments aboard the ISS will further assist educational institutions provide training and real-world experiences for undergraduates. Ultimately, this will help to ensure that the UK educational sector can offer the calibre of scientists required to meet the bioscientific challenges that further Lunar and Martian exploration will undoubtedly bring.

²⁶ National Curriculum in England: science programmes of study.

<https://www.gov.uk/government/publications/national-curriculum-in-england-science-programmes-of-study>

²⁷ Deane, C. and Szweczyk, N. (2019). Extraterrestrial Life Science. *The Biologist*, 64(4): 12-15.

<https://thebiologist.rsb.org.uk/biologist-features/extraterrestrial-life-science>

Summary: Bridging the Gap between existing capabilities and the access to opportunities to benefit the UK

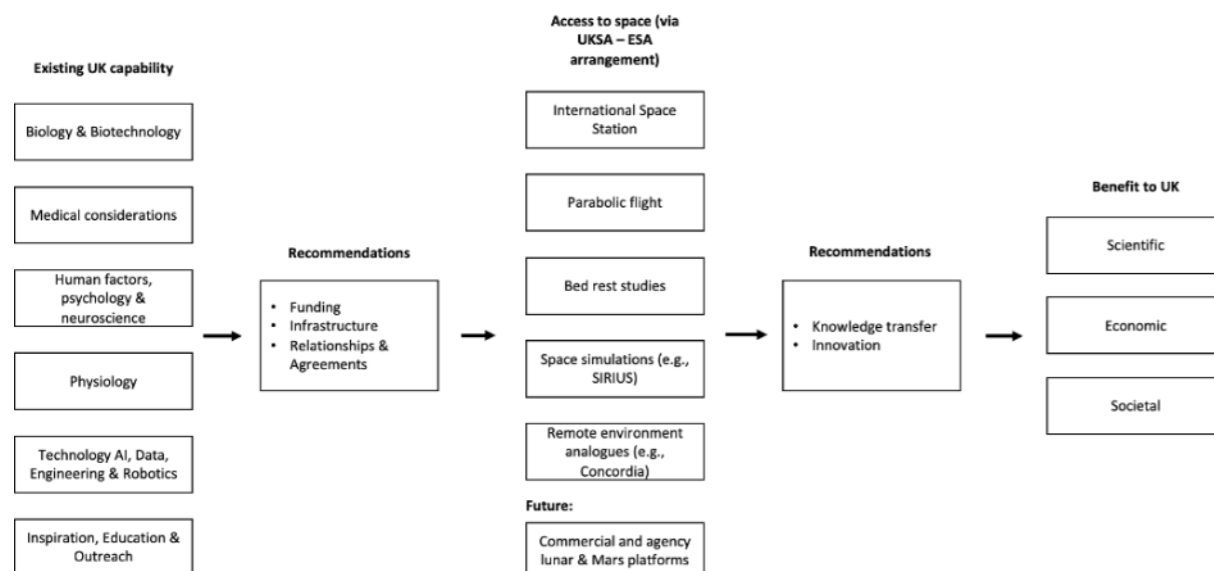
The UK has a world leading space R&D ecosystem and established partnerships with international agencies, in particular close strategic partnerships with the European Space Agency.

Specific to the health and life science sector, there exist significant capability across domains. This is evidenced by the previous thematic chapters and the considerable number of contributions received (see section 'Making the Case' [Pg 44]). The community also has access opportunities, directly, and through relationships with UK Space, to the various space platforms previously discussed, including the ISS, parabolic flight and ground based analogues. Similar access is expected to future platforms such as Lunar Gateway and Lunar surface infrastructure as well as various commercial testbeds. Eventually this may extend to deep space exploration platforms.

It is clear from the thematic chapters and underpinning individual author contributions, that a significant barrier to life and biomedical scientists in the UK being able to do space-related research for both exploration and terrestrial benefit is the lack of a bridging mechanism between capability and access. This is represented in the below Figure.

Without the right funding, infrastructure and relationships and agreements it is challenging for UK scientists to develop and sustain long-term research programmes in collaboration with the international agencies, principally ESA, and other commercial partners. This is problematic because it limits often necessary multi-year investigations that might be scaled up over time from studies in ground-based platforms to microgravity, and potentially in the future, to lunar and deep space missions. Recommendations outlined at the beginning of the paper offer a way forward and possible solutions for bridging this gap.

Space life and biomedical research conducted on space platforms, facilitated by the recommendations mentioned above, has the potential to benefit the UK across scientific (building capability and expertise), economic (supporting new commercial ventures and job creation) and societal (solving important societal challenges from ageing to resilience and mental health) domains. To secure this benefit, there has to be the right governance in place to enable effective knowledge transfer and exploitation.



Presently, the route through which to effectively document, translate, transfer and exploit knowledge generated from space life and biomedical science research by UK scientists is unclear. This is captured in the recommendations gap towards the right of Figure. Suggestions have been offered, including knowledge transfer initiatives and industry catalysts, which if taken up should maximise the potential impact of this research.

Overall, the aim of this paper was to highlight the groundswell of support for building capability and capacity in the space life and biomedical sector in the UK. A joined up process has been offered with clear recommendations, that if followed, would support the space life and biomedical sciences community and put the UK amongst the leading nations working on these topics.



"The interface between the Space Sector and the Health & Life Science Sector, could provide a powerful catalyst for new research and innovation. This report helps to lay the foundations for how the UK can harness its respective world leading capabilities in these respective sectors to drive R&D collaborations"

Dr Barbara Ghinelli
Director, Clusters and Harwell Campus Business Development,
UKRI-STFC

Supporters

Our thanks go to all the institutions and organisations which have supported this endeavour including:-



"The opportunity for new commercial applications developed in the microgravity environment is just opening up, and with the strength of UK lifescience research, there is a great opportunity for the UK to create new concepts and deliver significant social and economic benefits to earth!"



"KTN exists to connect innovators with new partners and new opportunities beyond their existing thinking – accelerating ambitious ideas into real-world solutions. Our diverse connections span business, government, funders, research and the third sector. KTN is fully supportive of this initiative to further harness the interface between the Space and Life Sciences sector, and to foster knowledge transfer and new cross-sector collaborations that accelerate ambitious ideas into real-world solutions".

About UK Space LABS

UK Space LABS was created in 2014 through the merger of the UK Space Biomedicine Association - a student lead organisation for the advancement of space medicine and life sciences in the UK - and the UK Space Biomedicine Consortium - a collaboration of institutions with space biomedicine related interests or activities.

The purpose of the association is to advance the research and conduct of space life and medical sciences and related sciences in the UK. Our members consist of clinicians, academics, government representatives, early career researchers and students, industry and military professionals.

Its core objective is to support the Space and Aviation Biomedical community in the UK through:-

1. Specific Events
2. Showcasing the speciality and examples of research at the national level
3. Articulating terrestrial benefits of this theme

To learn more about the association, visit ukspacelabs.co.uk or follow on,



Twitter: @uk_spacelabs



LinkedIn: UK Space LABS



Our sincere thanks to the entire UK Space LABS executive committee from this and previous years for their work advancing this sector interface.

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For questions relating to this paper you can contact the UK Space LABS engagement team on our above social media or by email on ukspacelabsengagement@gmail.com

"I have learned so much through my involvement with UK Space LABS. Many of their challenges are entirely new to me, and the solutions will benefit greatly not only the space sector but life on our planet"

Hagan Bayley
Professor of Chemical Biology, University of Oxford



Making the case for Why Space? The opportunity for Health & Life Science Innovation

Through the open calls in 2020/2021 over 50 contributions were received from Academia, Industry, Clinical and Government contributors. In the previous Thematic chapters a synthesis from these was presented. Here, the full contributions are collated which cover a breadth of activity and input from the Health & Life Science Community.

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1. Commercial services – fast-track access to microgravity

Dr Ramón Nartallo, Kayser Space Ltd.

Overview

Gaining access to microgravity facilities to perform experiments relevant to Biology, Medicine, Biochemistry, etc., is key to understanding the phenomena behind observed effects. This has traditionally required competing for space agency funding and flight opportunities; those successful, often waiting years for custom hardware to be designed, manufactured, space qualified and flown into space. Through the Bioreactor Express commercial service, Kayser is able to fast-track the development of customer experimental hardware and its deployment in the International Space Station (ISS). Working in collaboration with ESA, Bioreactor Express uses scheduled ISS-bound launches and provides exclusive access to the KUBIK incubator.

Related Case Experiences

Building on experimental hardware developed by Kayser for the successful ESA BIOROCK mission, the Bioreactor Express service was kicked-off with the BioAsteroid mission, a University of Edinburgh funded bio-mining experiment completed within a calendar year, that flew to the ISS with SpaceX-21 in December 2020. The automatic culturing devices were incubated in the KUBIK ISS facility for three weeks, allowing bacteria to grow on a substrate of biocompatible meteoritic material. The capsule splashed down in the Atlantic Ocean on January 14th 2021. At least two other commercially funded experiments are scheduled with Bioreactor Express in upcoming SpaceX flights to the ISS.

Impact and Terrestrial Benefit: Driving research and innovation

Through the current government investment in space ports, and the existing industry-leading manufacturers of small satellites and launch systems, the UK is uniquely placed to lead the commercialisation of access to space. With its own UK base, Kayser specialises in the development of bioincubators for space applications: hand sized laboratories equipped with electronics and mechanical parts that execute experimental protocols automatically, allowing for the growth, treatment and fixation of biological specimens cultured in microgravity. For us to be able to run a viable commercial service, the provision of life science experimental hardware needs to become more agile, standardised and much cheaper and quicker to implement. A market analysis and business plan based on actual demand for experiments on the ISS, shows that a viable commercial service such as Bioreactor Express will start to turn a profit within three years of operations. This is after taking into account the necessary initial investment in hardware devices and containers, that could be easily adapted to different life science experiments and flown multiple times. This approach removes the large costs and long lead times associated with hardware design, manufacture and qualification, thus making access to the microgravity environment affordable and fast.

Following this approach, Kayser is currently working with The Institute of Cancer Research and Imperial College London on the definition of three separate cancer research related experiments, where microgravity can provide a significant advantage. In all three cases, we are looking to define experiments that can be technically implemented by exploiting and/or adapting existing bioincubator technologies.

Going forward, Kayser, in collaboration with several leading UK universities, is embarking on a programme to develop sensors for bioreactors that would enable a range of in-situ analysis and monitoring activities of live samples, thus removing the requirement for samples to be brought back

to Earth. These advances would enable the deployment of fully autonomous bioreactor systems on other platforms (e.g. cubesats) and environments (such as the lunar surface or Mars) where sample return is not feasible.

Looking further ahead, Kayser has been selected by ESA as a “sub-aggregator” of commercial payloads for the Space Rider platform and there are similar commercial prospects for the future space Gateway. The KUBIK facility itself could be adapted to other Low Earth Orbit platforms that are under development to exploit the post-ISS era, such as Dreamchaser or the Dragon Orbital Capsule. The Bioreactor Express service itself will be extended through the development of experiment hardware with built-in sensors for deployment in external space platforms and free-flying cubesats.

2: Designing experiments for space: assisting the process

Gianluca Neri, Kayser Space Ltd.

Overview

This contribution to the “Why Space” paper reviews the context and approach to developing new space experiments in the field of the Life Sciences in the UK. The current means for funding and developing research experiments for flight on the available microgravity platforms are assessed, with particular attention to the role played by Space Agencies, both at national and international level. The share of UK-led investigations on the International Space Station (currently the most important platform available for microgravity research) and the strength and weaknesses of the UK R&D ecosystem are discussed, including the support provided by the public sector. In the conclusions, we address ways in which the process of conceiving and designing new experiments in microgravity could potentially be improved and exploited by the UK space community, and highlight how these endeavours can ultimately benefit society in general.

Related Case Experiences

The UK scientific community and industry play a leading role in space research and endeavour in general and, in the Health and Life Science sector, are particularly active in the fields of Astrobiology and Human Physiology. The UK has the potential to be a centre of excellence in astrobiology, its scientific community is largely constituted in the Astrobiology Society of Britain, with at least 24 academic institutions having centres, departments or institutes working in the field. The collaboration between King’s College and the RAF Centre of Aviation Medicine has produced intense research activity on fundamental questions regarding human physiological functions and adaptation during spaceflight, as well as impact on health. The outcome is a number of publications on gravity loading countermeasures systems. At Northumbria University they are actively working with the European Astronaut Centre (EAC) on Aerospace Medicine and Rehabilitation.

In terms of National programmatic support to Health and Life Science research in space, most of the UK’s involvement in human spaceflight and research is channelled through the European Space Agency (ESA). At the 2012 ESA Ministerial Council, the UK Space Agency made its first contribution to the International Space Station (ISS) and ESA’s European Life and Physical Sciences Programme (ELIPS). At the most recent Council (November 2019), an annual investment for £374 million over the next 5 years was pledged.

Despite the opportunity presented by the almost 10-year long partnership with ESA, only five of the 250 experiments carried out on board the ISS by ESA (as listed in the NASA Space Station Research &

Technology portal (www.nasa.gov/iss-science) are UK-led experiments, three of which have the same PI. Other UK-led experiments in the database were part of the UK's National Principia Mission, an educational / outreach activity performed during Tim Peake's long-duration flight, hence not subjected to a peer reviewed process. Given the excellent R&D level of the UK research institutions and technology innovators, there clearly is a mismatch between the strength and interest of the UK academic community in space life sciences and the limited presence of UK-led research programmes in the ISS. This is in turn compounded by the fact that the UK research councils have not traditionally considered supporting access to the ISS as they would for any other laboratory facility.

This relative lack of success in deploying experiments in space can only derive from the small number of successful applications, in part due to a poor level of awareness of what the space environment (and microgravity in particular) can offer, but also due to a lack of knowledge of and support available regarding the processes and procedures to access it. There is evidence of proposed projects that, while having a solid scientific purpose, lack an actually feasible implementation concept, or are not properly engineered for the space environment targeted, or fail to meet programmatic, logistics and/or cost constraints. In most cases, this is due to the experiment proposer not having deep knowledge of the demanding requirements and constraints of the space environment, or adequate support to circumvent this limitation. This is why UK industry with specialist knowledge in designing for space must be engaged at an early stage, in order to conceive feasible and effective programmes.

It is in this context that the 2020 call of the UK Space Agency for feasibility studies of new experiments in microgravity was very welcomed. Among the projects funded by this initiative, it is worth mentioning two new experiments in the field of the Life Sciences. One is led by the University of Liverpool, aimed at investigating whether mitochondria are the key regulator of muscle loss in microgravity conditions and during the ageing process on earth, with the aim of helping identify the nature of exercise protocols that can contribute to modify mitochondrial changes. These could be important findings for the prevention of physical frailty and the promotion of Healthy Ageing. A second study, granted to Imperial College London, focuses on tumoral cells replication and the effectiveness of drug delivery through an innovative class of nano-carriers based on graphene nanoplatelets doped with a nanostructured semiconducting material. The experiments conducted in microgravity will help determining the role of gravity behind the mechanisms of drug delivery. Both studies are supported by Kayser Space as the industrial partner, to derive the technical and programmatic feasibility of the proposed experiments. We believe this is the most efficient mechanism to promote research and innovation in space successfully.

Impact and Terrestrial Benefit: Recommendations and Conclusions

The public sector should invest in nurturing a culture of operating in space, by offering grants to enable Health and Life Science research that uses space as the test-bed for investigations that are not possible on Earth, but that nonetheless help to improve life on Earth.

We would also encourage the coordination between the UK Space Agency and National Research Councils, in order to promote the space environment as a next-generation 'laboratory facility' to be exploited in any research field, particularly where the lack of gravity can help unmask other processes at play. Through the recently established ISS commercial exploitation programme, access to state-of-the-art space facilities can now be gained by contracting a number of approved commercial suppliers, making the process of deploying a new experiment in microgravity eminently affordable and quick.

In addition, ESA member states participating in the ISS programme, which includes the UK, can have direct access to ISS resources for national experiments. Harmonisation of calls for research grants with a firm National microgravity exploitation plan would lead to outstanding programmes that, supported by expert industrial partners, could be deployed within a reasonable budget and tight schedule.

The potential terrestrial returns are undoubtedly attractive, as demonstrated by the two new

research studies mentioned above, including economic benefits that could derive from, for example, new drug delivery mechanisms in cancer treatment. Maturing theories, potential applications and valuable products all can arise from the knowledge and capabilities generated through new experiments designed for microgravity research activities. As this process unfolds, products and services derived from microgravity R&D are generating commercial activity and social benefits.

3. Dedicated Return: The Opportunity for Health and Life Sciences Off-ISS

Joshua Western – CEO, Space Forge

Overview

The benefits of conducting health and life science experiments in space have long been observed. The combined vacuum and microgravity environment, which cannot be replicated on Earth, have ensured space remains an environment where pharmaceutical, virological and pathological discoveries, treatments and potential cures can be accelerated. Since the inauguration of the International Space Station, the opportunities to access the space environment have grown immensely. From ESA experiments in nanoparticles to replace traditional antioxidants to commercial R&D from pharmaceutical companies such as Merck seeking to improve cancer drug delivery.

The ability to access the ISS for life science experiments can come in many forms - though national and commercial space entities. To a greater or lesser extent, all these platforms:

- Use shared infrastructure which can be subject to political interests
- Balance competing and often conflicting payload requirements
- Take up to 5 years for experiment approval
- Have long lead times to experiment commencement
- Have issues with achievable cleanliness and disruptions to microgravity from frequent maneuvers and dockings
- Offer limited ability for experiment return and the few vehicles that can return have hard landings

Space Forge is developing a platform for health and life science experimentation to overcome these barriers.

Opportunity

Low cost access to space, and the relative ease in which the environment can be exploited through the ISS and small satellites have fueled a new era of the space economy coupled with innovation. However, the missing lynchpin of a sustainable in-space ecosystem for research and development, is return. The opportunities to return from space are few and far between. They primarily rely on coming back from the ISS with solutions such as Dragon or Soyuz. ISS Capsules like Dragon only come back between 4-6 times a year, are difficult to access for commercial entities or small research platforms (astronaut constraints, national experiments etc.) and return at a highly accelerated G-load ending in a high shock impact as they land on Earth. A return solution which can offer gentle de-orbit and touchdown, coupled with extended stays in space off-ISS to access a superior space

environment would unlock new H&LS applications and R&D opportunities.

Space Forge is developing the ForgeStar suite of platforms. These platforms are deployed on a conventional launch to a minimum orbit of 500km for dedicated experimentation and R&D for individual customers. Our platform is designed to stay in space for any time ranging from 10 days to 6 months, when a precision commanded return is initiated. The ForgeStar suite will offer payload capacity from 3kg to 75kg. The ForgeStar can overcome the barriers and issues associated with accessing the ISS:

- Offer a dedicated platform for H&LS dedicated to a single user.
- Be compliant with BSL2+ research.
- Return on demand, preserving experiment integrity.
- Compatible with a range of applications such as fluid dynamics, protein crystallisation and lunar/planetary gravity simulation.
- Offer regular flight opportunities throughout the year.

Space Forge is transforming how health and life sciences can leverage the space environment for research and development. Our flight opportunities commence in 2022.

4. Children in Space? Planning for Children's Development in Space Environments

Prof. Dianne Catherwood & Prof. Graham K. Edgar - Centre for Research in Applied Cognition, Knowledge, Learning and Emotion (CRACKLE), University of Gloucestershire

Overview

Children will inevitably become members of space environments either as space natives or immigrants, facing potential developmental challenges in either case. Space communities may try to replicate terrestrial conditions and children may ultimately adapt to space conditions. Nevertheless, there may still be developmental hazards such as reduced gravity, ionizing radiation and restrictive habitats. Research with other species suggests that native space children may face risks to conception, prenatal development, birth and early postnatal survival, while evidence from astronauts indicates that immigrant space children may require physical and psychological adjustments. It is timely to begin serious consideration of policies, strategies and material innovations to support the safe, effective development of children in space.

Related Case Experiences²

There is no informed discussion as yet of the full spectrum of children's potential development in space conditions. Of course there are no case studies of children in space, but there is useful evidence for adult astronauts and the offspring of other species, highlighting risks from microgravity for muscular and bone strength and for sensory systems such as those for balance and vision.

Research on risky developmental environments on Earth also offers insights. For example, children raised in institutions that restrict early exploratory behaviour have poorer sensori-motor development, while childhood radiation exposure leads to physical malformations including of the

brain. Similar concerns arise from research regarding effects of restrictive developmental environments for other animals, such as visual deficits resulting from limited visual conditions in early life.

Such evidence highlights the need to plan for appropriate developmental environments in space, especially to enable:

- Protection from ill effects of microgravity and radiation on physical growth
- Support for vestibular- proprioceptive (balance) and movement development with exercises, tools and child-friendly spaces
- Appropriate stimulation for sensory development (e.g., adequate illumination and stimulation for colour, pattern and depth vision and ways to prevent ocular changes from microgravity)
- Educational programmes providing skills and knowledge for the local space conditions (e.g., terrain and astronomical environment).

Impact and Terrestrial Benefit: Driving Research and Innovations

We are preparing a manuscript and book on these issues, drawing on our research backgrounds in developmental psychology, cognitive neuroscience and human factors in aerospace. To expand the discussion however, an invitation could be extended to agencies and academics to develop working papers, publications, an online presence, workshops and research projects. There is no group currently addressing children's general development in space, although Developmental Psychology groups and the UK and other Space Agencies could encompass this concern. For example, it may fit within the focus of the International Space Life Sciences Working Group (NASA, ESA, etc.) on reproductive and early biological development in space.

Alongside the fundamental aim of protecting the well-being of children in space, there is considerable potential here for innovative technologies and techniques for supporting children's space development. For example, children's postural and movement development requires interaction with the physical environment, but this may be hazardous in space habitats and terrain. Nevertheless, materials could be designed to support this development in space, such as protective and flexible apparel, child-friendly mobility devices, toys and games adapted to low gravity and child-focussed space habitats. Such items may also prove of terrestrial value for children with movement disabilities.

In sum, a seminal group is needed to develop ideas, policies, publications, research and materials to plan for and support the development of children in space. Failure to fully consider this issue may lead to poor developmental outcomes in space colonies and possibly the loss of those communities.

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5. Situation awareness is an issue wherever you are

Prof. Graham K. Edgar & Prof. Dianne Catherwood Centre for Research in Applied Cognition, Knowledge, Learning and Emotion (CRACKLE), University of Gloucestershire

Overview

The 'human factor' has long been recognised as one of the most significant factors underlying errors and accidents and is an area that needs further consideration for space programmes. As equipment becomes increasingly reliable, the humans operating it stay the same. Space environments will provide new and unusual challenges for all task components (human and machine). Having a human in the loop provides the possibility of novel and creative problem-solving in unusual situations. Unfortunately, humans can bring the same creativity to errors. The literature carries many examples of 'fool-proof' systems that have been severely compromised by the ingenuity of humans.

The ideal system, from a human factors point-of-view is one that requires no instructions to operate. It is so intuitive that the operator will 'naturally' use it correctly. The next best option is to have a system that the user (through training or even from reading the instructions) understands fully. To do this, the user has to be aware of the right information at the right time (note, this is not the same as the information being potentially available) and, crucially, understand it.

Having an awareness of the right information may be referred to as 'situation awareness' (SA) whereas making sense of it is 'situation understanding' (SU). We believe that both are crucial to effective operation in any environment, but especially so in space. A lack of SA and/or SU in space operations and conditions may lead to potentially life-threatening errors.

Related Case Experiences²

We have developed models of, and methods for measuring, SA and SU and these have been successfully applied to improving performance in safety-critical situations, such as firefighting (see, for example, the FireFront project: <https://firefront.eu>), obstetrics and command and control.

Uniquely, these techniques allow assessment of SA and SU, together with individual tendencies to

accept or reject information as being relevant to the task. This latter measure is important, as a tendency to reject information as irrelevant means an operator is likely to overlook something important, whereas a tendency to accept too much information carries the danger of overload – and missing important details in the 'noise'. Furthermore, we have developed measures that compare what individuals think they know against what they actually know. A disjunct between these two aspects of SA/SU can underpin some truly catastrophic errors.

The FireFront project has demonstrated the utility of SA measures by revealing that there may be cultural differences in aspects of SA; something that may be important in applications (such as in space) where teams are multi-national and multi-cultural.

Impact and Terrestrial Benefit: Driving Research and Innovations

Optimising SA and SU carries enormous benefits in terms of reducing errors with the consequent loss of equipment and even life. Our measurement techniques can be run as simple procedures on a variety of platforms (even mobile 'phones) that can be used in training and also for users to self-test their own information-handling biases – providing insights applicable across a wide variety of situations. Such testing and training could be applicable to all those involved in space programmes – in whatever capacity.

We wish to highlight the importance of human factors in space and are further developing the techniques described above to link in with the underpinning neuroscience, to develop remote monitoring of brain activity to identify 'danger states' when the chances of errors are increased.

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6. Life sciences and microgravity

Daniel Campbell - SpacePharma Limited

Overview

The microgravity environment of space provides unique conditions for better understanding of physiologic and pathologic processes and has a substantial scientific, technological, and commercial potential which is leading to a paradigm change and a revolution in life sciences and health-related applications.

Studying the physical chemistry of macromolecules in reduced-gravity environments enables research in the absence of gravity-induced surface constraints, convection, shear forces, sedimentation/stratification, and hydrostatic pressure.

Such studies can promote elucidation of protein 3D structures, improvement of protein crystallization, development of new monoclonal antibodies, the discovery of new drug polymorphism, self-assembly of biomolecules, pharmaceutical studies of microencapsulation, drug delivery systems, behaviour, the stability of colloidal formulations and more.

The microgravity in space also affects all levels of biological organisation, including cells, tissues, organs, and organisms, often in unique ways. Thus, microgravity and space research enable new understanding of living systems and novel directions of pharmaceutical research.

The fact that biological systems are modulated in space allows identification of novel pathways that regulate gene expression, enhance stem cells proliferation and differentiation.

Additionally, ageing and prolonged microgravity exposure during spaceflight share some notable detrimental effects on human physiology making the microgravity environment a unique, attractive and accelerated, non-invasive tool for developing new anti-ageing and neurodegenerative diseases therapeutic treatments. Also, bacterial virulence, pathogenicity, and resistance to antibiotics have been shown to increase in space.

Related Case Experiences

The accumulated experience on board the International Space Station (ISS), as well as on board SpacePharma's launched satellites, demonstrates the considerable advantages offered by microgravity in understanding the mechanism of antibiotic drug resistance by bacteria and the potential for discovery of new antimicrobial agents.

An experiment designed by Professor Lee Cronin, the University of Glasgow Regius Chair of Chemistry and Founding Scientific Director of the Cronin Group Plc, has been launched to space over SpacePharma's satellite, seeing digital chemistry being trialled in space for the first time.

The UK Space Agency has been recently making funding available for feasibility studies into possible UK-led experiments that could be carried out and deliver high-quality science on the International Space Station (ISS) or other commercially available microgravity and space environment facilities, such as SpacePharma's satellites and microgravity labs.

Under this grant, SpacePharma and the Cronin Group have conducted a study dubbed "Space ChemPU", which was concerned with optimised automation of chemical synthesis in microgravity, a key process for new drugs generation. Next phases will include an in-orbit demonstration/validation and platform commercialisation.

Impact and Terrestrial Benefit: Driving research and innovation

The knowledge gained through microgravity research can facilitate drug screening and improve drug design, delivery, and storage, thereby contributing to the development of new technologies and therapeutic products.

Another area of innovation is the improved space-grown tissue engineering of human organoids in the absence of gravity in tailored organ-on-chips, as preferred ex-vivo pharmacological models for screening of new drug candidates.

Drug companies have already been performing drug research on accelerated models for osteoporosis and muscle atrophy, protein crystallization, vaccine development and other fields of research. Such advances are expected to greatly contribute to new advances with applications both in space and on Earth.

Microgravity in space offers a wealth of new opportunities in the era of space commercialisation for innovative, affordable, accessible, autonomous, and unmanned microgravity lab platforms mounted on remotely controlled small satellites, new Space shuttles and Space stations.

SpacePharma UK-based operations leverage existing and evolving sovereign UK capabilities to build, launch to orbit, operate and even safely return such microgravity laboratories. Its Space-proven remotely controlled miniaturised lab platforms can also have valuable terrestrial applications, especially in harsh and hazardous environments. With one of the strongest pharmaceutical sectors globally, the UK is poised to leverage and lead microgravity research and manufacturing.

7. Space Psychology and Human Factors:

Dr Iya Whiteley - Centre for Space Medicine, University College London, UK

Overview

Since Margaret Thatcher withdrew UK participation in the Human Space Flight programme, and before the UK Space Agency was formed, one of the first case studies in Life Sciences in the UK was our ESA funded General Study Programme, Tools of Psychological Support during long duration missions to the Moon and Mars. This study was fundamental in creating a Technology Readiness Level-based roadmap and systematically mapping out the areas of psychological and social support techniques and technologies required in preparation for exploration missions beyond Earth's orbit. Many of techniques and technologies have been since advanced to be used in space and applied in terrestrial settings.

Related Case Experiences

- Case Study 1: ESA study, Tools of Psychological Support during long duration missions (Dr Iya Whiteley, Principal Investigator (PI), 2006-2007): Defined a range of tools aimed at providing psychological support to the crew during long-duration exploration missions. The investigation started from identifying the type of issues the crew will need to deal with. Then groups of interacting factors were systematically identified within the Psychological Issues Matrix (i.e. Psy-Matrix), which trigger the issues. The existing astronaut psychological support model was extended and the Embedded Psychological Support Integrated for LONG-duration missions (EPSILON) was defined. A new model of psychological support model of astronauts proposed and roadmap for technology developed agreed with ESA experts.

- Case Study 2: ESA Study, IO: Expert Tool to Support Crew Autonomous Operations in Complex Human Spacecraft (Dr Iya Whiteley, PI, 2008-2010): The study outlined user and system requirements and prototyped a creative problem solving tool, Crew Expert Tool IO (CET IO). Designed for crew autonomous operations during future long-duration exploration missions to the Moon and Mars, CET IO was intended to use only available resources on the mission. Great considerations were taken to account for capabilities and limitations of executive cognitive functions during safety and time critical situations. CET IO was successfully tested with three ESA astronauts at NASA's Johnson Space Center.
- Case Study 3: VULCAN – Voice and content analysis tool to detect fatigue in exploration missions to the Moon and Mars (Dr Iya Whiteley, PI, 2016-2017): VULCAN was designed to identify crew members state of well-being in their natural operating environment without intrusive testing and any requirement for crew time. This toolset, through periodic analysis of the crew member communications designed to predict onset of fatigue and other well-being parameters and signal to the mission control. The user did not require special expertise to interpret the VULCAN analysis results.
- Case Study 4: iVOICE – Voice analysis to detect fatigue in astronauts (Dr Iya Whiteley, PI, 2012-2021): Monitoring, detecting and predicting unsafe for operation levels of fatigue is fundamental to prevent incidences and accidents in professions where human lives are at risk, in domains such as aerospace, mining, transportation and medicine. UCL Centre for Space Medicine and Psychology & Language Sciences (Prof Mark Huckvale) are leading the development of this non-intrusive, objective and accessible technology for mobile devices – iVOICE. It assesses fatigue through a short audio recording. Originally designed for space operations, over the past two years iVOICE has already been successfully trailed in the mining industry and did have initial testing in real-time operations in the aviation industry.

Impact and Terrestrial Benefit: Driving research and innovation

COVID-19 pandemic isolation and restrictions in external support and physical movement conditions parallels future settlements beyond Earth Orbit and vice versa. Funding is required to expand our understanding of how to prevent deterioration through continuous improvement of our well-being in independent-reliant living conditions; how to tap into and develop our human potential, exceptional capacities demonstrated in extraordinary conditions, investigate self-mastery achieved by time-honoured contemplative practices, using only nature's resources, sounds, movement and breathing, for example, forms of meditation, yoga, qigong and acupressure.

Subtle shifts occur in levels of consciousness, cognitive resources and states of well-being when people are moved to new operational environments and new living conditions. These shifts are not so subtle when unprepared and in the absence of a regular restorative practices. As a human race, we have recently experienced these shifts affected by the global pandemic situation. These changes will also affect future space settlers. How well we, as a human race, adapt to new living conditions now and in future Solar System exploration missions will depend on how prepared we are to recognise and acknowledge the onset, to monitor and treat it.

Going forward, work by UK scientists should explore what we already know about human attunements to new environments and how to be proactive in holistic prevention, monitoring and restorative methods to address these challenges. For deep space, we need to investigate potential shifts occurring in physical, mental and spiritual well-being and changes in interaction among Earth mission support (rather than a control) centre and exploration crews living and working in their extra-terrestrial contexts.

Ultimately, this work would prepare us to venture into deep space and meet challenges we face on Earth now and in the future.

8. Physical requirements for long-term spaceflight and extra-terrestrial colonisation

Dr Martin Braddock FRSB, FRAS - Sherwood Observatory, Nottinghamshire

Overview

The physiological ramifications of living and working in microgravity and at elevated exposure levels to space radiation have been well documented. Exercise regimes and therapeutic intervention strategies have been devised and implemented to reduce soft and hard tissue atrophy during spaceflight. Nevertheless, effective countermeasures for both physiological and psychological effects of long-term (>6 months) space travel in microgravity to permit establishment and colonisation of lunar and Martian habitats at <1 x g remain significant challenges. Moreover, adapting habitats to an environment where exposure to radiation is within acceptable life-time exposure limits will be pivotal for the construction and maintenance of ergonomically sustainable environments capable of supporting an acceptable quality of life for both astronauts in flight and for future colonists of other worlds.

Related Case Experiences

- Work by UK based scientists throughout the UK network of astronomy societies has contributed publications which advance scientific understanding of the application of the drug discovery and development processes to tackle problems associated with long term space travel.
- International collaboration of scholars has provided input into and publication of thought papers conceptualising the challenges associated with lunar and Martian colonisation and the role psychology and an understanding of human psyche may play in astronaut selection and maintenance of a harmonised and optimised environment.
- Members of the Royal Astronomical Society's Policy Group have contributed to the development of the UK Research and Development Roadmap¹ which includes input for Future frameworks for international collaboration on research and innovation and the establishment of the UK Advanced Research and Invention Agency (ARIA).

Several examples include:

- Crowd-sourcing of ideas from amateur and semi-professional astronomers drawn from 22 UK astronomy societies has operationalised and published the application of socio-technical systems models for the potential colonisation of Mars².
- Newton's Astronomical Society and Sherwood Observatory has consulted SMEs and published on the challenges facing the development of space medicine, the opportunities afforded by the space environment for drug discovery and the potential role of human enhancement to facilitate long term space travel^{3,4}.
- Provision of UK input into thought paper generation and publication⁵⁻⁸.

Impact and terrestrial benefit: driving research and innovation

In concert with the case study provided by Dr Nathan Smith, we would propose involvement of the broad scientific community in training and providing research facilities for graduates, post-graduates and doctoral level scientists on:

- Drug discovery and development as applied to space travel and for the benefit of patients on Earth
- The potential for human enhancement for risk mitigation strategies
- Communication and outreach to the general public on the application of UK based technology and expertise to problem solving, exemplifying the potential for space harboured research to benefit humankind

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9. Human spaceflight research and sport & exercise science: interactions and synergies

Associate Prof Adam Hawkey - Solent University Southampton

Overview

Sport and exercise science provides insights into how humans can perform in a variety of settings and helps to address a number of issues relating to health and human performance including:

- how to enhance athletic performance;
- how the body responds to physical activity;
- how to prevent and treat sporting injuries;
- how to prevent and treat chronic diseases;
- how the body reacts to extreme environments.

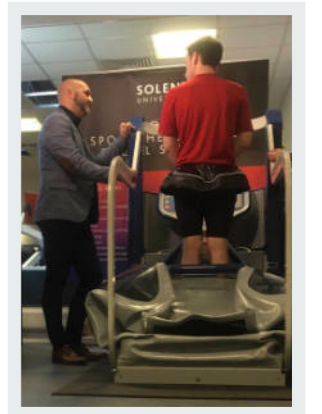


Image Courtesy of Adam Hawkey - Solent University Southampton

Exercise forms a crucial part of human spaceflight and continues to be used as a countermeasure against the negative physiological impact of prolonged stays in micro- and reduced-gravity environments. There is a scientific synergy of using human spaceflight to model ageing on earth, with bedrest studies regularly used to help predict the long-term effects of spaceflight on a variety of human systems. Reloading of the musculoskeletal and cardiovascular systems after spaceflight and in 'return-to-play' scenarios in sport both offer an opportunity to address the reduced physical fitness (e.g., bone density, aerobic capacity, muscular strength and endurance) experienced and better understand how this impairs human performance, and increases injury risk. Research conducted in a space-based environment, including the development of new technologies and training protocols, can therefore directly benefit those in a terrestrial environment; and vice versa.

Related Case Experiences

Solent University has a thriving sport and exercise science department, and staff are currently involved in a variety of projects that would benefit from the opportunity to be further involved in space-related research. These projects are focused on the application of principles learnt from research investigating the physiological effects of human spaceflight and the technology developed to improve astronaut health, performance, comfort and efficiency. Two main themes of investigation currently underway within the Faculty of Sport, Health and Social Sciences are:

- Application of whole-body vibration training (WBVT) and hand-held vibration training (HHVT) to improve health and athletic performance (1-6)

The use of WBVT, believed to have been first developed as a training tool for early cosmonauts, has now been widely incorporated into the training regimes of recreational and elite athletes. Solent staff continue to be actively researching, publishing, and disseminating knowledge on the application and efficacy of WBVT and HHVT.

- Exposure to reduced gravity levels during rehabilitation from lower-limb injuries (7,8)

Working with Olympic/Paralympic athletes and English Premier League/English Football League teams, Solent staff are assessing how training under reduced levels of gravity (>0.2 g), using a specialised anti-gravity treadmill, can be used in both the performance enhancement and rehabilitation of athletes.

Impact and Terrestrial Benefit: Driving Research and Innovation

The importance of physical activity on both our physical and mental health has been heightened due to recent events surrounding COVID-19. In addition, physical activity is now regularly used to improve patients' fitness prior to surgery, and to help combat epidemics such as obesity and diabetes; all of which are helping us to live healthier lives, for longer. At the other end of the spectrum, high performance sport is embracing, and benefitting from, scientific research; as a result, the current scope and demand for the application of sport and exercise science in a variety of contexts continues to grow. In the future, greater research collaboration and knowledge exchange activities between the UK human spaceflight and sports science and rehabilitation communities would be welcomed. Ultimately, this increased communication and cooperation, on research projects, product design, teaching, and outreach, could have a beneficial impact on science, society and the economy of the UK.

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10. Microalgae biotechnology for space applications

Dr Matthew P. Davey¹, Prof. Alison G. Smith², Dr Payam Mehrshahi², Ellen Harrison^{2,3},

Dr Felice Mastroleo³ & Dr Natalie Leys³

¹ Scottish Association for Marine Science, UK

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Overview

Microalgae are photosynthetic microorganisms that have the potential to provide a large number of human life support functions during space flights and on lunar or Martian bases. They would provide health benefits in terms of vitamin, antioxidant and other micronutrient supply as well as crucial functions such as waste regeneration through carbon sequestration, oxygen evolution and food production. In addition, they could provide organic material for artificial soils should the lunar and Martian substrate be used as a mineral basis for growing plants (i.e. in situ resource utilisation). Experiments on microalgae have been performed in space since the 1960's and more recently on board the ISS, where there are plans to expand the capacity to enable more advanced experiments and research of these organisms.

Given the growth in the space sector, the UK is at a pivotal point in leading fundamental, translational and applied algal research for the health and life support space systems (e.g. within ESA SciSpace Roadmap 7 - Supporting human habitation in hostile space environments). There is also a very strong international focus on lunar exploration and countries are adapting their strategic agenda to be part of it. For example, algal research falls under the current ESA programme remit to "Establish what is required to enable life (microbes, plants) to survive in the lunar environment". It is very likely that the first European (possibly UK) experiments to grow species on the moon will be with microalgae.

Related Case Experiences

The UK is a world leader in academic (eg. UKRI BBSRC Algae-UK network) and commercial algal biotechnology and product development and is well placed to taking the lead to advance R&D in this sector. For example, researchers at the University of Cambridge (Smith, Davey, Mehrshahi, Harrison) carry out fundamental studies on how vitamins (e.g. B12) are exchanged in algal-bacterial communities and together with SCK CEN Belgium (Leys, Mastroleo) exploiting these communities for long term space missions to maintain and improve crew health (funding by the ESA MELiSSA POMP programme); researchers at the Scottish Association for Marine Science (Davey) and SCK CEN Belgium (Leys) and Bristol (Robson-Brown) are looking to study how variation in the life cycle and pigment content of different algal species can be exploited to improve cell survivorship during long term space missions.

Impact and Terrestrial Benefit: Driving research and innovation

Algae are increasingly being used as a source of human food and nutrition, fuel and bioremediation on Earth. However, the biology and processes for enhanced growth, monitoring and scale-up is far from optimised. The information gained from conducting experiments and the use of algae in space for human health and life support systems will drive new and exciting research and innovation in this

sector. For example, efficiencies made in microbial strain selection, bioreactor design, growth monitoring and harvesting for the space sector all have translatable and commercial terrestrial applications.

The cluster of algal researchers, enterprises and companies across the EU and in the UK mean that there are potential partnerships that can successfully accelerate these terrestrial applications. In order to achieve this, and for the UK to maintain and increase its presence in this sector, we view as imperative a new coordinated programme that facilitates access to, and interactions between, bioreactor engineering and operation optimisation, robotics and satellite engineers, algal physiologists, astrobiologists, molecular (micro)biologists, modellers and health and medicine experts.

11. Bioengineering development of human respiratory life support systems for use in space.

Dr Patrick Magee PhD, FRCA, Retired consultant in anaesthesia - Royal United Hospital, Bath | Past visiting lecturer, University of Bath | Director, Magee Medical Systems Ltd.

Overview

Respiratory support of human life is required in both hospital and inhospitable environments. In hospital, mechanical ventilation or pressure breathing is delivered to critically ill or surgical patients. Similar technology is used to support spontaneously breathing users in adverse terrestrial or extra-terrestrial surroundings. This requires an appropriate gas mixture to a mask-wearing firefighter, diver or mountaineer, or to an aviator or astronaut in an enclosed, pressurised suit or helmet. The breathing system must provide physiological oxygen partial pressure, excrete carbon dioxide, be capable of accommodating partial pressure changes, minimise respiratory work and provide thermal neutrality. In all cases, monitoring is required for oxygen, carbon dioxide and other gases, in both local atmosphere and user.

Related Case Experiences

Because UK involvement in human presence in space to date has been limited, it is not surprising that there is no evidence of UK manufacturers in that field of life support, as there are in US, Russia and Europe. There are UK companies like Luno and 3M Scott, who make breathing hoods and pressure breathing masks for industrial settings, and companies that make breathing equipment for diving, such as JFD or Lungfish, and UK medical ventilator manufacturers like Breas, Dyson or Penlon. With the right interdisciplinary research input, these companies could adapt their expertise and infrastructure to development and manufacture of space life support systems. Otherwise, a future UK human space industry will have to rely on the extensive experience of overseas companies like ILC Dover, Cobham, NPP Zvezda or Dräger.

The author's experience with respiratory technology includes almost forty years in clinical anaesthesia and intensive care, with a background in biomedical engineering. In the past he has undertaken consultancy work on medical life support systems for use in space with Wyle Labs USA and with the European Space Agency (2001 – 2003)⁽¹⁾; and more recently (2020) with several UK companies on ventilator technology for use in the Covid crisis. His research at University of Bath, Department of Mechanical Engineering, includes a PhD on mathematical modelling and clinical testing of low flow breathing systems (2014)^(2,3), and mathematical modelling of shared ventilator

breathing systems for use with Covid patients (2020)⁽⁴⁾.

Impact and Terrestrial Benefit: Driving research and innovation

With appropriate cooperation, historically lacking between experienced clinicians, respiratory physiologists and engineers, the technology which is already available for hospital and inhospitable terrestrial applications described above, could be adapted and developed for use in the inhospitable environment of space. Appropriate interdisciplinary bioengineering research has the capability to produce the very best quality systems for users in all environments. It is believed that the expertise available at Bath University, can assist in the development of the technology described, to the mutual benefit of both the space sector and the clinical sector in the UK, both areas typically underserved by UK developers and manufacturers.

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12. Optimising movement for safe and effective human performance in space

Prof Maria Stokes, Dr Martin Warner & Paul Muckelt - University of Southampton

Overview

Long-duration missions to Mars will require specific inflight training, to optimise performance of manual tasks prior to surface planetary excursions. Recommendations from the ESA Topical Team on Postmission Exercise (Reconditioning) in 2016, stressed the importance of this preparatory training (preconditioning). In the absence of live video teleconferencing between astronauts and medical/training staff on the ground, astronauts will need to self-manage their preconditioning and reconditioning.

The effects of long-duration missions on the human body are largely unknown but astronauts will need to prepare for reloading on joints in partial gravity, compounded by weight of the spacesuit and equipment. We can learn from our terrestrial research on quality of movement with elite athletes and military populations to protect joints from injury and optimise performance.

Assessment of movement performance would inform Go/No Go criteria for planetary excursions, ensuring the astronaut can perform tasks safely, accurately and effectively in a coordinated, controlled manner. Interactive technology (sensors, algorithms, visual feedback) could produce meaningful results and self-management plans.

To be effective, this research concept will require multidisciplinary collaboration, using bio-psycho-social models, including behavioural theory. Partial gravity simulation will be needed, e.g. parabolic flights.

Related Case Experiences

The Southampton team (M Stokes, M Warner, P Muckelt) has three strands of research that would be integrated to achieve the proposed system (outlined in the overview above) for optimising movement:

1. ESA Myotones project (lead D Blottner, Berlin; UK researchers supported by UK Space Agency/Science & Technology Facilities Council, STFC). This involves monitoring astronaut (ESA/NASA) muscle health via remote guidance throughout 6-month ISS missions. This project has provided valuable lessons for virtual clinics with patients on Earth during the Covid-19 pandemic.
2. Interactive system (Phase 1) for assessment/training of manual tasks, embedding movement sensors in a body-worn suit (with D Green, King's College London; R Vaidyanathan, Imperial College; STFC & FortisNet-funded),
3. Southampton leads international research on assessment and neuromuscular training for movement quality in athletes and military personnel.

Development of the proposed interactive system would focus on enabling muscles to produce effective, coordinated movement, whilst integrating monitoring of muscle health.



Image Courtesy of Maria Stokes: Remote guidance of ultrasound imaging of muscle on ISS (Myotones Project) Credit: ESA & University of Southampton

Impact and Terrestrial Benefit: Driving research and innovation

Facilities similar to the European Astronaut Centre (Cologne) would enable collaboration of UK-wide groups. A dedicated funding pathway would provide continuity following preliminary studies. A Centre infrastructure would produce critical mass, and enable capacity building with a career pathway for innovative young minds to flourish and become world-class space research leaders.

Common themes between UK human space research groups ready for exploitation include: musculoskeletal health, prevention and management of back pain, optimising performance. The proposed approach will enable targeted preconditioning and reconditioning to prepare for missions to outer space.

Potential benefits to people on Earth include: prevention of premature frailty with ageing; mobility after prolonged immobilisation, particularly spinal injury; and patients with long-term neuromuscular and musculoskeletal conditions. Technological advances would benefit remote management of patients, to accommodate limited healthcare resources; a need that was accelerated during the Covid-19 pandemic.

13. Life sciences research for space exploration and habitation

Dr Timothy Etheridge¹ & Prof Nathaniel J. Szewczyk²

¹College of Life and Environmental Sciences, University of Exeter, UK.

²School of Medicine, University of Nottingham, UK.

Overview

There is a new and unprecedented global drive to explore and colonise other planets, with the World's Space Agencies and several private companies all vying to ultimately place boots on the Moon and Mars. With this comes an urgent need for detailed understanding of the molecules regulating spaceflight maladaptation. This is because exposure to radiation and microgravity (amongst other environmental stressors) seriously reduces human health that would compromise longer-term mission performance. However, the precise causes of space-induced health decline are poorly understood and, consequently, effective therapies remain elusive. Given the inherent uncertainty surrounding health during prolonged microgravity, a strong space life sciences programme is an essential component of any safe and realistic human space agenda.

Related Case Experiences

Researchers at the Universities of Exeter and Nottingham have conducted multiple biological experiments onboard the International Space Station (ISS), including the upcoming 'Molecular Muscle Experiment 2' that is the first UK National ISS payload. Using the small worm *C. elegans*, these projects are establishing the reproducible molecular causes of negative health changes in space, and the efficacy of novel drug and genetic treatments.

Impact and Terrestrial Benefit: Driving research and innovation

Access to space and new research technologies in deep space are two key barriers to establishing a strong UK space life sciences platform. Commercial space access is gaining traction and various companies offer flight opportunities across ESA's newly defined mission priorities: LEO, the Moon and Mars. Commercial partners provide ISS experiment implementation support, and NASA are

commercialising future Moon contracts. Utilising UK-based space implementation partners, combined with appropriate funding frameworks for science activities by the UK Space Agency and/or UKRI will nurture expanding UK expertise in space life sciences. Moreover, Agency/UKRI funded programmes that facilitate technology development (e.g. life support, novel analytical capabilities, multi-organism hardware) will provide the infrastructure to maximise science- and geo-return.

In particular, understanding the molecules causing space-induced health decline, such as with our 'Molecular Muscle' experiments, are necessary to develop targeted countermeasure development. New space therapeutics will also hold relevance to analogous conditions on Earth, including ageing and health loss during bed rest/inactivity. Moreover, realistic human space habitation will require remotely deployed 'telemedical' health therapies. The essential need to develop new telemedicine technologies in space will have important Earth impact, for example in the defence sector where medical treatments during remote operations are critical to mission success, just as they are with prolonged space travel. New technologies for deep space life sciences, including our recently developed miniaturised, remotely operated hardware for real-time in vivo fluorescent imaging in flight, will allow examination of the feasibility and in vivo efficacy of novel telemedical interventions, such as synthetic drug/biology approaches. Similarly, novel life sciences solutions in space, such as miniaturised DNA/RNA sequencing, provide new methods for prominent issues on Earth including remote virus (COVID-19, Ebola) research and surveillance.

14. Investigating the effects of micro- and hypo-gravity on musculoskeletal deconditioning

Prof Jim Richards - Allied Health Research unit, University of Central Lancashire

Overview

The development of decomposition EMG to study neuromuscular deconditioning was pioneered by Professor Carlo DeLuca of the Neuromuscular Research Centre at Boston University. This has previously been used to explore the effects of microgravity on the neuromuscular control signals into the muscles by decomposing EMG signals into their constituent Motor Unit Action Potential Trains (MUAPs). This technique was applied to work funded by NASA (grant 99-E192), which tested astronauts returning from the International Space Station. This highlighted changes in the individual Motor Unit (MU) firing rates within lower limb muscles on return to Earth, and provided an insight into why muscles not only weaken in space but also exhibit poorer motor control after prolonged exposure to low gravity environments. This is an important issue that is relevant for enhancing the safety of astronauts in space and improving their health during and following extended exposures to microgravity.

This technology has continued to develop and it is now possible to wirelessly monitor and decompose a larger pool of MUs, which can be used to determine how their behaviour is modifiable under different conditions. This may provide a way of monitoring deconditioning, and perhaps more importantly, to develop training protocols to regain neuromuscular control quickly and efficiently. Previous terrestrial work using the decomposition of EMG signals has shown that motor unit (MU) behaviour may be recorded using surface EMG which can yield information such as MU recruitment thresholds, firing rates and amplitudes. Previously this has been restricted to isometric tasks, and has shown that different isometric loads change the MU recruitment thresholds and firing rates which has been used to explore the effects of muscle training, and the effects of age. Recent literature now suggests that such detail on motor unit behaviour can now be identified during cyclic dynamic

contractions of muscles in the upper and lower limbs, however only a few studies have been conducted exploring the differences in motor unit behaviour during concentric and eccentric muscle contractions, and little or no data exists on how this behaviour changes with speed.

Reflection on previous activity in the field (where pertinent/available) include:

- Previous work by Professor Nick Caplan et al explored spinal musculoskeletal deconditioning using intramuscular electromyography (EMG) during parabolic zero G flight.
- Professor Carlo DeLuca et al tested astronauts returning from the International Space Station providing an insight into why muscles not only weaken in space but also exhibit poorer motor control after prolonged exposure to low gravity environments.

Related Case Experiences

Researchers at the University of Central Lancashire currently have a program of work exploring MU behaviour during the concentric and eccentric phases of different exercises performed at different speeds and loads. This has shown the influence of the load, movement speed, and type of contraction on motor unit behaviour in relation to the neuromuscular demand. These insights highlight, for the first time, the effect and interaction of these modifiable factors on MU recruitment which help to explain their respective roles in motor control and force production, and their importance in the monitoring of muscle deconditioning. To consolidate and build on this work, we have strong clinical links and relationships with relevant commercial partners.

Impact and Terrestrial Benefit: Driving research and innovation

The links between muscle deconditioning in space flight and terrestrial muscle atrophy experienced by different patient groups highlights interesting parallels between the MU recruitment required to provide the optimum rehabilitation exercise dosage, and that of reducing or preventing muscle deconditioning during space flight. Our work, and the work of our academic and commercial collaborators, provides a thriving community of biomechanists, physiologists, clinicians and innovators, some of whom have previously been involved in space-related projects. The developing technology to decompose EMG signals is of growing interest in the assessment of patients with different musculoskeletal and neuromuscular conditions. One example of this is our work with Clinical Neurophysiologists, which is exploring the use of such techniques as novel neurological assessments, and their use when traditional clinical physiology assessments are difficult to perform.



15. The use of wearable robotics/ exoskeletons to assist movement in different environments and rehabilitation

Dr Matthew Dickinson - University of Central Lancashire

Overview

Exoskeleton systems have been traditionally focused on manufacturing and their military applications however, during the development of these systems small members of the research community looked to develop exoskeletons for the sole purpose of clinical applications. Recently modern manufacturing techniques such as additive layer manufacturing (ALM) have offered a huge potential to lower the costs of these devices. In addition, developments of geometry and fabric actuation offer the possibilities of reduced size, weight and power consumption offering a greater muscular assistance whilst not compromising performance. Studies have shown that during space flight astronauts can experience up to a 20% reduction in muscle mass over a 10-days, to counter this problem large exercise training areas are often set up on the craft, however this relies on these exercises being performed correctly to provide sufficient activation of the muscles to reduce atrophy. By introducing the exoskeleton system, the potential of designing not just assistive but also resistive forces could introduce an equivalent muscle usage for astronauts in various gravities.

Related Case Experiences

Researchers at the University of Central Lancashire along with joint partner Tinus Olson are working on the introduction of new AM produced Exoskeletons for assistive clinical use. Using the benefit of AM technology, the design of these systems has considered muscle function, comfort, and ease of maintenance. This work has recently developed into a new approach combining a hard passive structure alongside a soft fabric approach to minimise weight and power consumption.

Impact and Terrestrial Benefit: Driving research and innovation

July 20th 1969 the first man walked on the moon, this was a huge achievement for humanity. From this leap numerous developments have been accredited from the fire fighters suit through to the common handheld vacuum. Our next big step is the mission to Mars, the health of an Astronaut is imperative if we are ever to achieve a goal such as this. By using AM technology, the maintenance, modification, and production of components during active missions is possible. However, this also has many applications outside of space flight with the most apparent to the wider population being health care. Exoskeletons can come with a high price tag, this limits the accessibility of this technology as organizations such as the NHS and other health services cannot justify the funding required to support these. Through the introduction of AM technology manufacturing costs can be dictated by the methods used for production of the equipment. This approach can be used not only to support large loads, but also allow assistance in fine control of an individual's movements. These may be provided through fine control of the actuation of the system alongside the associated muscle activations allowing the control of these movements, thereby creating a controlled sympathetic motion of the joints, and ensuring the muscular system remains both protected and actively used. Such systems may not only provide improved performance of fine movements under loads but would also be able to provide significant benefits in the targeted rehabilitation of specific muscle groups of the spine, upper and lower limbs.

16. Functional optics as ultra-lightweight 3d printed space components

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Overview

3D printing has changed the way we design and fabricate. A key challenge for successful space missions is to keep the launch costs practical by minimizing the mass [1]. The main reason for investigating 3D printing for space applications is the many fold reduction in mass that is possible. Apart from mass reduction, other space requirements include ability to fabricate bespoke shapes; use of materials that are operational under radiation, temperature swings, and having low outgassing, i.e., low total mass loss (TML) in vacuum; and robust assembly. These requirements can be fulfilled by 3D printing. Optics form a key component of all space missions as visual characterizations are crucial for the success of space health and life sciences missions. So, can 3D printing be utilized to create functional opto-electronic devices for space?

3D printing for space is being explored, e.g., 3D printing a lunar base [2], machine shops at the ISS [3], and 3D printed telescope [4]. Two main aspects of testing 3D printed devices for space are: 1) launching printed devices in space to characterize their functionality, 2) printing devices while in space in microgravity. The first phase, to evaluate the effects of space environment on 3D printed devices; that are fabricated on earth and launched in space, is an urgent study. An understanding of the effects of being in space and microgravity on polymers, optical coatings, and the 3D printed parts is critical. Furthermore, the ability to print functional devices, perhaps down to the nanoscale, is an area that requires focused efforts [5].

Related Case Experiences

Vaidya et al. [6] was the first to demonstrate design and fabrication of 3D printed optics using desktop 3D printers. This technique created high-quality aspheric microscope mirrors, concentrator arrays, and immersion lenses.

An application for 3D printed and carbon fibre reinforced polymer (CFRP) optics is Space-based Solar Power (SBSP). The main requirement for viability of a SBSP system is high specific power (power/mass), necessary for keeping launch costs practical. An ultra-lightweight parabolic mirror design and fabrication process based on using cast CFRP parabolas with the UV gel surface smoothing technique, to produce mirror surfaces with nanometer scale surface smoothness was conceptualised [7] and created successful space prototypes.

Impact and Terrestrial Benefit: Driving research and innovation

Many technologies were first adopted in the context of space, before making it to terrestrial systems; and we expect the same to be true of this technology. 3D printed optics will bring down the cost and complexity of traditional fabrication processes and find new applications in: augmented & virtual reality (AR & VR) optics, cameras, imagers/displays, adaptive optics, solid-state lighting, solar concentrators, and more. 3D printed polymeric lenses open up new applications in AR: optics, photonics sensors, and waveguides.

Especially relevant to the COVID-19 pandemic, it is vital to create space colonization technologies to preserve our human civilization. Lightweight optical devices form an important aspect of these space technologies. Specific life sciences applications are plentiful, e.g., photonics sensing of biomolecules [8] and creation of lightweight microscope optics [6].

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17. Translating the lessons of remote work and prolonged isolation of astronauts to the modern day workforce of the new normal

Dr. Marcus Ranney - Founder and CEO Human Edge

Overview

The pandemic of 2020 has highlighted the competitive advantage that wellbeing provides, especially the important role in psychological health for the workforce. A “sledgehammer” approach to curb the virus, has resulted in greater than 50% of the world’s population living in lockdown; the World Economic Forum calling it the greatest psychological experiment ever conducted. The Climate crisis is a catalyst for global health challenges and Covid-19 may be the start of a trend of climate driven changes that continue to pose increasingly hazardous situations which will impact mental, emotional, psychological and physical health for years to come. But there are a group of professionals that routinely work in confined, stressful environments with high expectations on physical performance and mental agility; astronauts. This is the moment to take the learnings from this profession, over the past five decades, and apply it to our terrestrial work-life.

Reflection on previous activity in the field (where pertinent/available) include:

- A paper published in 1990 considered the mental and psychological effects on the future crew of the Space Station Freedom (precursor of the ISS), suggesting humans part of its “complex system”. Preparing for crew rotations of 180 days, its authors were well aware of psychological factors needed to be monitored.
- Previous investigations revealed consistent results with crew suffering from anxiety, boredom, depression, sleep disturbances and psychosomatic manifestations; many of which impaired productivity, performance and their overall health.
- Since then, Crew Psychological Training (CPT) and Isolation studies are now a routine aspect of crew selection and training to optimise for mission success, increasing in importance as longer term space missions are planned in the coming years to the Moon and Mars.
- Terrestrial based staged environments include analog studies being conducted on long duration simulated missions at NASA’s Extreme Environment Mission Operations (NEEMO), Russian based NEK, Antarctica’s research stations and analog facilities in the UK.
- Between 2007 and 2011, three crews of volunteers participated in a simulated Mars isolation study, called Mars-500, supported by NASA, Russia, China, and ESA.
- In March 2019, international participants in the Scientific International Research in a Unique terrestrial Station (SIRIUS)-18/19 project spent four months in isolation.
- China has run a series of small-crew isolation experiments at their simulated Lunar Palace 1 facility

Related Case Experiences

Over the past few months, a few business media platforms have articulated similarly themed suggestions. Professors Noshir Contractor and Leslie DeChurch, from Northwestern University, published an article on “What Astronauts Can Teach Us about Working Remotely”, which had a focus

on teamwork, group dynamics and maintaining energy levels. Forbes Magazine interviewed a number of astronauts (Captain Scott Kelly, John Grunsfeld PhD, Dr. Chiao) and Bill Paloski, Ph.D., Director of NASA's Human Research Program to review aspects of confined living quarters, physical distancing and remote working and its effect on productivity and performance².

Impact and Terrestrial Benefit: Driving research and innovation

Remote working is part of the new normal. Whilst significant efforts have created reactive processes, the majority being done in an unprepared manner, a lot are far from ideal with negative consequences.

The UK's Health and Safety Executive³, in 2017, published a 'Thriving at Work' review and various other UK government departments have since issued guidelines on mental health suggestions for organisations, many of which were released in 2020. Whilst the majority of this work is focused on protecting the UK workforce, major corporations are looking to develop frameworks and tools to help assist the 'Return to Growth Agenda'. A second, and larger, application of this hypothesis is to optimise remote working as space missions are routinely used to work at a distance (mission control to spacecraft), time delay (communication delay between messages) and technology dependence (bandwidth, signal quality, etc).

This can lay the foundation for organisations like UK Space Labs, and others involved in the areas of developing human related spaceflight capabilities, to work with public and private sector stakeholders to create an effective translational piece of work needed to adapt the data from extreme environments (or staged earth based controls) to the current lockdown challenges and help companies better manage their workforce and governments come up with more effective planning measures for when this strategy needs to be extended.

The economic consequences of not doing so would be monumental and governments should view this activity as part of its strategy for maintaining global relevance, strategic importance, competitiveness and growth.

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18. Protecting the health of astronauts using the principles of astronautical hygiene

Dr John R Cain - Space Consultant (Astronaut health)

Overview

Since the beginning of manned spaceflight, there has been a need to protect the health of the astronauts from exposure to the physical, chemical, biological and psychological hazards of living and working in space. Astronautical hygiene (AH) is recognised by space scientists as a branch of occupational medicine that aims to control astronaut hazard exposure (see references below). The principles of AH are to characterise a hazard, to assess the exposure health risks and to determine the measures to mitigate exposure. Such principles are used by Government scientists, academics, researchers and business to:

- determine and assess the health effects associated with exposure to extreme hazards, such as lunar dust, in the UK, the USA and the EU;
- design and implement mitigation techniques to control hazard exposure;
- undertake and participate in research on working and living in space;
- act as a lynchpin in the application of the space sciences and provide a holistic approach to protect astronaut health; and
- advise Governments such as the UK Space Agency on hazard risk management strategies and related cost-effective mitigation measures.

Related Case Experiences

Lunar dust is jagged and abrasive. Dermal exposure to the dust can cause skin damage. Researchers in the cosmetics industry have been using simulated lunar dust to investigate skin cellular changes. The data collected is being used by biochemists, toxicologists, astronautical hygienists and others to determine the levels of skin damage and to establish a better understanding of skin disease and the aging process in particular in weightlessness conditions. AHs are evaluating the data to evaluate the exposure health risks and to develop risk management strategies for both terrestrial and extra-terrestrial skin applications.

It is expected by the aerospace industry that space tourism will become profitable in the future. Commercial space companies are working with researchers in the industry, including AHs and engineers, to design and implement effective life support systems to ensure homeostasis during short term space travel. Projects are underway in the development of such life support systems in particular on the use of effective and efficient extraction systems. The first stage test trials indicate positive results should be available within the year.

Impact and Terrestrial benefit: Driving research and innovation

Astronautical hygiene and space medicine are the two major disciplines that are applied at all levels terrestrially and extra-terrestrially to successfully ensure the health of astronauts. Workers in the field of AH include toxicologists, physiologists, psychologists, medics, engineers and others. Such workers are mainly financed and promoted by academia, industry, NASA, ESA and other relevant stakeholders. Because AH is effective in assessing health risks both terrestrially and extra-terrestrially

to protect the health of astronauts, it is growing in significance in the space industry. There is therefore a need to pool biomedical/engineering knowledge under the one discipline of AH for greater overall efficiency. In addition, many peer-review papers, include topics in space biomedicine and hazard mitigation measures; but when designing the initial research methodology there is a failure to integrate the principles of AH. Research workers therefore tend to work in isolation. There needs to be improved communication and resource provision within the space science/medicine communities to improve this. This would benefit research for example, in the study of mechanical measures to prevent eye problems developing in weightlessness conditions, or the effects of gravity on dust deposition in the lungs.

There are several Universities and establishments in the UK, as well as abroad, where individual topics of AH are studied. This may be as part of a space science course, as part of a research project or as a post-graduate dissertation (for example, at King's College, Northumberland Uni, UCL, Sherwood Observatory). There is no educational establishment that teaches the principles of AH as a single discipline. This has resulted in a separation of the teaching of the biomedical from the mechanical engineering aspects of the discipline. In the short-term, therefore, funding for AH should be made available from a combination of academia, the professional bodies, Government, industry and Government agencies to promote the subject in pre- and post-graduate studies. Once the terrestrial and extra-terrestrial benefits of the discipline are recognised and seen to be driving research and innovation in the space sciences then stakeholders and partnerships may provide additional finance to ensure that the UK remains a future key player in the exploration of manned space travel.

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19. Muscle wasting and human spaceflight

Dr Richard Skipworth - Royal Infirmary of Edinburgh, University of Edinburgh

Overview

Cancer cachexia is the syndrome of muscle wasting and nutritional depletion experienced by cancer patients. Cachexia reduces patient treatment response, worsens physical function, reduces quality of life, and ultimately results in shortened survival. It is estimated to directly cause up to 50% of all cancer-related deaths and is therefore an enormous healthcare burden internationally.

Almost all cancer patients experience cachexia towards the end of life, but we are increasingly recognising the importance and negative clinical impact of cachexia at the beginning of the cancer journey, even in those patients receiving treatment with curative intent. Equally, we know that cachexia affects many other patients with chronic illness (e.g. COPD, heart failure, kidney failure, HIV etc). However, our understanding of the pathophysiology of muscle wasting in cachexia remains incomplete, and studies performed in animal models often do not translate to the human patient. Furthermore, we do not yet have an agreed or licensed efficacious management strategy for patients with cachexia.

Muscle wasting is also a condition experienced by humans under microgravity conditions. Astronauts experience significant muscle wasting during long duration spaceflight, which then impacts on their ability to function when entering an environment with higher gravity (e.g. return to Earth or potential mission to Mars). Effective countermeasures to counteract muscle wasting is a key challenge of long duration spaceflight. Astronauts, and terrestrial bed rest analogue studies, represent unique opportunities to investigate muscle wasting in humans (biochemically, physiologically and functionally). Further insights into the mechanisms and negative functional consequences of muscle wasting would help develop treatments for both astronauts and patients with cachexia, with important beneficial functional impacts for both groups (e.g. safety, mission effectiveness, and task completion for astronauts, and independence, quality of life and survival for patients).

Reflection on previous activity in the field (where pertinent/available) include:

- Researchers at the University of Edinburgh represent one of the key leading international research teams for cancer cachexia, especially with regards to translational and human studies.
- Members of our team are involved in leadership positions within the Cancer Cachexia Society; international consensus initiatives on disease definition and functional endpoints; and international programmes for cachexia education and training research. Members of our team are also members of the National Institute for Health Research (NIHR) Cancer and Nutrition Collaboration, and Society on Sarcopenia, Cachexia and Wasting Disorders.
- Many syndromes of muscle wasting share similar potential mechanisms of muscle wasting, especially with regards to end-effector mechanisms of intramuscular protein wasting. However, the potential crossover with microgravity-based research is an underexplored area of research need.

Related Case Experiences

Researchers at the University of Edinburgh are involved in tissue banking programmes for surgical and palliative care cancer patients (including tumour, muscle, fat, blood, urine), which are used in funded programmes of mechanistic translational research, often with international or industry (e.g. Novartis) collaboration. Funders include Cancer Research UK and Medical Research Council. We also lead multinational clinical trials of multimodal and novel interventions aimed at muscle recovery in

cancer patients, involving the robust nutritional and functional characterisation of recruited individuals (e.g. anthropometry, body composition analysis using cross-sectional imaging techniques, and assessment of muscle function by various techniques including physical activity meters). Such clinical trial interventions include exercise and nutrition as key components, an approach which will be of obvious importance in the prevention of muscle wasting for astronauts.

Impact and Terrestrial Benefit: Driving research and innovation

Advances in the generation of human models of muscle wasting (e.g. study of astronauts or bed rest volunteers) would provide valuable insights into the mechanisms and treatments of muscle wasting that are not easily available in the UK. Research in this area would provide two distinct health benefits with inherent scope for innovation. Firstly, the development of successful microgravity countermeasures or muscle therapeutics for astronauts would lead to international collaboration amongst space agencies with the potential for widespread adoption, including commercial space ventures. Secondly, the development of therapies would have major terrestrial impact in a range of human diseases, including cancer, providing major opportunities for pharma collaboration. Key aspects of current muscle/physical activity research include the use of wearable sensor technology with further scope for industry partnership. Such a strategy would sit well alongside capacity-building research structures in the UK, such as the NIHR Cancer and Nutrition Collaboration.

20. Medical Devices Utilisation and Connectivity with relation to Human Spaceflight

Mr Ashfaq Gilkar - Lead Clinical Business Analyst, Guys and St Thomas' NHS Foundation Trust.

Overview

Satellite communications/GPS are an important aspect of medical devices connectivity in the UK with various projects being instigated seeking to establish connectivity between ambulances & A&E/ Ambulance HQ. The ability to download patient results from within an ambulance ensures rapid decision making at the receiving Hospital leading to improved clinical outcomes & the potential to save numerous patient lives. The opportunity to utilise the incumbent 5G wireless communications technology in the medical devices connectivity arena is substantial & this provides a robust connectivity platform in real-time with reduced delay or 'lag time' in messaging. The utilisation of satellite communications technology would be all important in establishing a robust & reliable communicable integration between human spaceflight, Cube Sat's and terrestrial bases.

Remote monitoring & viewing (such as 'telemedicine'/google glasses' & similar visual aids) being an important aspect to the above whereby two way visual communication between terrestrial and space flight missions could be established providing a platform for sharing data, provision of expert instructions and immediate uploading of astronaut diagnostic or clinical investigative data for assessment by mission control. The instigation of robotic automated processes & also incorporating AI/ machine learning tools to enable predictive analytics associated with astronaut diagnostics & clinical investigations performed during missions.

Related Case Experiences

1. A collaboration between GSTT and London Ambulance Service led to a study using on-line Point

of Care Testing diagnostic devices within an Ambulance setting prior to entry to the hospital helping front line staff accelerate decision making, reduce congestion, improving patient waiting times. Online POCT would be a mainstay of human spaceflight missions.

2. The GSTT Pharmacy department RACS APOTECA robotic arms project for automatic formulation of patient medication. Utilisation of similar robotic devices on Human Spaceflight missions to automate tasks & assist astronauts with manual tasks.
3. Remote viewing of XLTECH EEG monitors within ICU departments of GSTT at the peak of the Covid-19 pandemic. Establishing Citrix based remote monitoring of monitors by clinicians to avoid and minimise excessive clinician exposure to Covid-19 infected patients.
4. CogStack - low cost structured - unstructured information retrieval & extraction architecture utilising AI/Machine learning capabilities within GSTT providing an open source integrated document retrieval & information extraction, to solve a variety of typical issues associated with analytics within an NHS environment. This concept could also be applied to Human Spaceflight scenarios.

Impact and Terrestrial Benefit: Driving research and innovation

Nurture closer collaborations between the NHS & UK Space Agencies, via an infrastructure framework implemented to support UK-based NHS Healthcare staff & scientists to conduct research with international space agencies & relevant commercial partners. This would provide the funding & partnership opportunities for established, early career & clinical researchers to engage in responsive, stakeholder-driven & innovative medical devices connectivity for human spaceflight research.

Partnerships being established via the following means to foster closer working ties between the NHS community and UK Space Agencies:

- Seminars, webinars and conferences related to spaceflight biomedical research topics to be held within & hosted by large UK teaching hospital NHS trusts.
- Incorporation of UK Space Agencies and their contributions as co-authors or partners within NHS based research papers and as acknowledged part of research studies.
- Invitation of UK space agency staff to relevant NHS conferences/seminars and vice versa.
- Identifying key persons or 'champions' within the NHS that have an interest in Human Space flight related topics and encouraging these to join the Space Agencies /Community.



21. Printed tissues in space

Prof Hagan Bayley - University of Oxford, UK

Overview

Modern medical treatments span a spectrum from small molecule therapeutics to biotherapeutics (e.g. monoclonal antibodies) to cell-based therapies (e.g. immunotherapies) to transplantation. The diversity of people and their ailments suggest that a comprehensive collection of such medicines cannot be stored on a space craft or space station. All but the most mundane treatments will have to be manufactured on demand.

Our lab in Oxford is engaged in the fabrication of tissues, both synthetic and living, which will contribute to emerging medical therapies. By synthetic, we mean materials that mimic living tissues, but do not contain cells that can divide. The synthetic tissues are built by 3D printing and contain thousands of aqueous compartments that can communicate with each other and with the external environment. By using multiple printing heads, patterned tissues are produced from compartments with different contents. These materials mimic aspects of living tissues. For example, they can transmit electrical signals or change shape.

By using a related printing technique, we also fabricate tissues by patterning living cells in three dimensions. The cells are printed at high density and remain fully viable. After printing, they can divide, differentiate and migrate. Stem cells and genome-edited cells can be used, and their organisation can, but need not, resemble that found in nature. Hence, the printed cells can mimic natural tissues or behave in a novel fashion.

Related Case Experiences

Fundamental research on fabricated synthetic and living tissues is supported in Oxford by an ERC grant on 'Remotely-controlled functional synthetic tissues' and an Oxford Martin School programme entitled '3D Printing for brain repair' in which neural tissues are produced by printing reprogrammed human stem cells.

Impact and Terrestrial Benefit: Driving research and innovation

We are currently generating synthetic tissues with medical applications, such as implantable materials that produce molecules (such as therapeutic peptides) when signalled to do so by an external signal, such as a local magnetic field. Further, we are producing tissues for the repair of damaged organs or to substitute for failed organs.

Clearly, there are challenges if this technology is to be reproduced in space. Can we make printers that will function correctly in low gravity? What is the minimum set of reagents that will be needed to be stored to produce printed tissues in space? Certainly, astronauts will have to have with them frozen vials of tissue progenitor cells derived from their own stem cells.

Besides providing solutions for space medicine, the means to prevail over these technology challenges in space will provide benefits here on Earth. For example, the fidelity of the delicate process of tissue printing is likely to be improved in a controlled gravity environment and the ability to carry out sophisticated medical procedures in harsh environments or countries with poor infrastructure will be enhanced by following procedures that succeed in an isolated space craft or settlement. In addition, the growth of precisely patterned 3D tissues under microgravity will contribute to our understanding of important fundamental principles in developmental biology.

22. Psychology and Human Spaceflight

Dr Nathan Smith - University of Manchester

Overview

Psychology provides a lens through which to understand the mind and behaviour of astronauts. This is important because in space astronauts are exposed to an unusual and highly challenging environment characterised by a range of potentially stressful physical, psychological and social demands. As a result of these demands, the space environment can impact upon the safety, health and performance of astronauts. Amongst other contributions, psychological studies have previously informed astronaut selection, development of methods to ensure effective stress adaptation and coping, how to optimise ground-crew interactions, and design approaches to ensure that those flying in space survive and thrive during their expeditions.

Reflection on previous activity in the field (where pertinent/available) include:

- Researchers from the UK have been actively involved in studies related to psychology and spaceflight. This has included conducting both fundamental and applied research projects in collaboration with ESA, NASA and other associated partners and stakeholders.
- Previous work conducted by scholars in the UK has contributed to advancing scientific understanding, led to countermeasure innovations and been used by agencies during current and future mission planning. There is also evidence of terrestrial benefit, with findings from psychological studies of astronauts being applied to support the UK military and most recently the covid-19 pandemic response.

Related Case Experiences

Researchers at the University of Manchester and Manchester Metropolitan University are currently conducting several psychological projects with ESA and NASA. This includes research on cosmonaut motivation during 6-month missions on the ISS, the development and validation of a standard psychological assessment for performance and health monitoring on exploration class space missions, and methods for monitoring biopsychosocial function and resilience during the Mars simulation SIRIUS confinement studies.

Impact and Terrestrial Benefit: Driving research and innovation

We have a thriving community of psychologists in the UK, some of whom are already engaged in space-related projects. Today, UK psychologists continue to shape the future of human spaceflight by providing expert input to new ESA human research roadmaps, developing technologies and infrastructure to allow ESA and other agencies to monitor the psychosocial function of personnel involved in space and space analog missions, and providing critical mentorship to young and early-career scientists interested in pursuing work in this area. There is clear downstream terrestrial benefit of work being conducted by UK psychologists focused on space. Studies conducted by researchers in the UK both in space and on space analog platforms have been translated and led to the development of tools and technologies for safety management in high reliability industries (e.g., mining), resulted in evidence-based resilient performance training and education for extreme occupational groups (e.g., MOD, NHS), and informed resources on coping with isolation and confinement, most recently for those living in lockdown during the covid-19 outbreak.

To consolidate and build on this work, we would like to see a centre similar to 'The Translational Research Institute for Space Health (TRISH)' that can support UK-based psychologists and

behavioural scientists (and the wider scientific community) to conduct research with international space agencies and other relevant commercial partners. This type of centre would provide the funding and partnership opportunities for established, early career and pre-doctoral researchers to engage in responsive, stakeholder-driven and innovative psychology and human spaceflight research. Growing a vibrant and resilient community working in this area means that the UK would be well-placed to provide expertise in support of future agency and the newly emerging commercially operated space activities and missions. Ultimately, this should have a positive scientific, economic and societal impact to the UK and its residents. Much like with the TRISH model, advances stemming from support for psychology and human spaceflight research could, where relevant, also be translated to terrestrial settings.

23. Space Medicine in the UK

Dr Peter D Hodkinson¹ & Dr Rochelle Velho²

¹ Aerospace Medicine and Physiology Research Group, Centre for Human and Applied Physiological Sciences, King's College London (KCL)

² University of Birmingham NHS Trust, UK

Overview

Aviation and Space Medicine (ASM) is concerned with all factors affecting the human body in flight in health as well as sickness. It includes consideration around physiology, psychology and performance, which can provide critical input to countermeasures to protect against the harmful effects of their abnormal environment. Other aspects include medical system planning and clinical management of diseases secondary to exposure to extreme environments like space.

ASM was recognised as a medical speciality in the UK by the General Medical Council (GMC) in April 2016 and the training curriculum was formally ratified in September 2016. For many ASM is a sub-specialisation additional to their primary speciality, such as anaesthetics, general practice or emergency medicine.

There is a designated route to train medical personnel in ASM, although still in its infancy. The UK has world leading life science research institutions with a small but active space life sciences research community and a rich history of aerospace vehicle and life support system development and production.

Related Case Experiences

The UK has much of the required aeromedical infrastructure to support human space flight activities, for example, a human centrifuge, hypobaric chambers, thermal chambers, and disorientation chambers. However, they have not historically been readily accessible for space related research or training due to organisational access or lack of supportive fundings opportunities. There is not a UK parabolic flight capability or analog test and research platforms, although access is possible through ESA programmes. Multiple spaceports may be built in England, Scotland, and Wales, which could support both vertical and horizontal launch capabilities and would require appropriate medical support.

The UK Space Agency does not have medical personnel, there is no central coordinating area or funded role in the UK for space medicine trained personnel. The CAA have been directed to develop regulatory policy to oversee human spaceflight activities but do not have dedicated space medicine personnel for this, although like the Royal Air Force they have started training personnel in ASM to

address this. Additionally, UK Space Agency research calls are typically limited to those with terrestrial health benefits or applications.

Impact and Terrestrial Benefit: Driving research and innovation

Space medicine is a key enabler of human spaceflight and is a fundamental consideration in any planning of crewed space operations. Research in support of human spaceflight can also be of wider benefit to terrestrial patients in the National Health Service. Hypersonic flight and sub-orbital launch offers a unique environment to study the human body and UK industry will need ASM support developing these vehicles and associated protection systems. These developments would also provide novel UK military operational capability and associated export potential. Research is also needed in this area to inform Civil Aviation Authority (CAA) medical regulations and support safe operations.

The key requirement that is missing is the political will and policy direction that would facilitate UK medical personnel and research to support human spaceflight operations. Following clarity on the political vision and intent, one way forward would then be the foundation of a centralised space medicine centre of excellence. This could be within the UK Space Agency or established as a virtual institute drawing in expertise from current centres of ASM excellence like the RAF Centre of Aviation Medicine, CAA medical department, industry and academic centres. This would help bring together space medical experts in the UK to develop a roadmap to prioritise research, facilities, funding streams, coordinate training and focus on building on our strengths in Space Life Sciences Research and Development.

24. Medical aspects of commercial suborbital spaceflight

Dr Thomas Smith - King's College London, UK

Overview

Very few people have ever flown on suborbital flights, which will soon be available to members of the public. Suborbital flight profiles entail novel physiological challenges, going in a matter of minutes from high G acceleration to microgravity and then back to high G. The forecast population that will initially be taking suborbital flights is very different from traditional astronaut or test pilot populations that are carefully selected and highly trained. Suborbital space travel is ultimately expected to revolutionise global transportation. For example, the Swiss investment bank UBS (total assets ~ \$1 trillion) recently notified investors to expect very fast suborbital space travel to be 'cannibalising' long-haul air routes within the next decade (e.g. London–New York in 30 minutes), while the US investment bank Morgan Stanley (total assets also ~ \$1 trillion) recently forecast \$800 billion in annual sales for suborbital point-to-point travel by 2040.

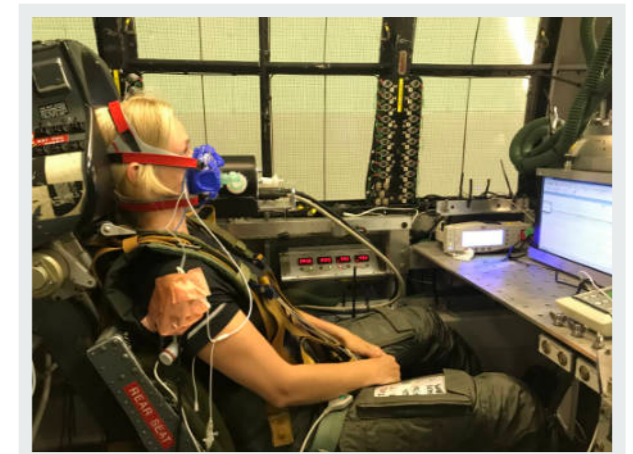


Image courtesy of Thomas Smith, King's College London

Related Case Experiences

Dr Thomas Smith is Head of Aerospace Medicine Research at King's College London and Consultant Anaesthetist at Guy's and St Thomas' NHS Foundation Trust. He is a Fellow and Council Member of the Aerospace Medical Association and an Academician of the International Academy of Aviation and Space Medicine. Dr Smith leads an international research collaboration exploring the physiology and medicine of commercial suborbital spaceflight. A grant from the UK Space Agency enabled experiments to advance UK technology that also provided novel data regarding the effects of high G on the lungs. Led by King's, this work was conducted in collaboration with the University of Oxford, QinetiQ, the Royal Air Force Centre of Aviation Medicine and RWTH Aachen University. Sustained high G acceleration at magnitudes relevant to suborbital launch and re-entry caused profound changes in respiratory physiology including hypoxaemia (lowered blood oxygen levels). This work did not replicate actual suborbital G profiles, which will be relatively brief, but was able to characterise underlying respiratory responses that may be triggered to some extent during flights. This research made use of advanced and invasive measurement techniques on a human centrifuge including direct arterial blood sampling under high G. These are the first studies to use electrical impedance tomography, diaphragm electromyography, oesophageal/gastric manometry, molecular flow sensing or concurrent hypoxia during +Gx (chest-to-back) acceleration, as experienced during space launch and re-entry.

Impact and Terrestrial Benefit: Driving research and innovation

The respiratory effects identified in this research could become clinically important in suborbital passengers who are particularly susceptible either due to advanced age or conditions such as obesity or smoking-related lung disease. At least initially, there is expected to be a tendency towards older age groups among suborbital passengers, and such comorbidities are likely to be relatively common. It is important from a regulatory perspective as well as training and protection for passengers that we have a better understanding of the physiological and medical challenges posed by these flight profiles, and further studies are required. This requires research funding which, in the field of space physiology and medicine in the UK, is often categorised as support for either 'research focussed on people going into space' or 'research with potential terrestrial translational benefits'. Unusually, research in suborbital medicine/physiology fits both categories – suborbital travel will eventually affect us all – and this work strongly warrants further investment.



25. Modulating the astronaut's microbiome during long space missions

Dr Franklin L Nobrega - University of Southampton, UK

Overview

Astronauts face many challenges on long-duration space missions, among which the difficulty of maintaining a balanced gastrointestinal (GI) microbiota. The GI microbiota – a large and complex community of microbes including bacteria, fungi and viruses – is critical for our health, with roles in digestion, maintenance of gut barrier function and modulation of the immune system. Thus, disruption of the normal functioning of the GI microbiota can lead to an impaired immunity and predispose astronauts to illness. In space, all measures are taken to minimize the risk of infections for astronauts. However, the lack of microbial intake from food and air – as it normally occurs on Earth – may have a detrimental effect on the diversity of the astronaut's microbiota. Adding the physical and environmental stresses faced by astronauts in space, significant alterations to the GI microbiota may occur. A weakened or altered microbiota can be exploited by opportunistic pathogens pre-existent in the gut and previously harmless due to competitive displacement by commensal GI microbes, to rise and colonize the gut. Importantly, studies demonstrate that several bacteria change their behaviour and virulence under microgravity conditions, heightening the concern about space infections. Currently the recommended countermeasure to deal with bacterial infections in the International Space Station (ISS) is the administration of antibiotics. But the large spectrum of activity of antibiotics will also do substantial damage to the commensal members of the microbiota. Once again this predisposes astronauts to colonization by pathogens and to illness, such as chronic or extreme diarrhoea.

Related Case Experiences

The use of probiotics has been proposed to help replenish the GI microbiota during and after antibiotic treatment in astronauts; but these only provide a limited selection of commensal GI microbes, since they are not supplemented by environmental microorganisms as on Earth. To avoid dramatic changes in the composition of the astronauts' GI microbiota we propose the use of (bacterio)phages as an alternative to antibiotics for treating space infections. These viruses of bacteria are highly specific, with their activity restricted to the bacterial species and most often strain level. Because of this, phages act only on their target bacteria, leaving the healthy microbiota untouched. They thus hold promise as a therapeutic alternative in space infections. Importantly, they may also be used as a preventive measure towards the overpowering of commensal bacteria by opportunistic bacteria, to maintain a healthy microbiota in astronauts on long-duration space travels. Researchers at the University of Southampton are currently conducting several projects with phages. This includes research into the efficacy and safety of phages as a treatment for antibiotic-resistant infections, the use of phages for the prevention/treatment of disorders associated with an imbalanced GI microbiota, and ways to prevent the development of phage resistance.

Impact and Terrestrial Benefit: Driving research and innovation

There is a clear terrestrial benefit of work conducted with phages in space. Understanding how extreme conditions such as microgravity and radiation influence the interactions between phages and bacteria will help us develop more effective phage therapies on Earth. The immune system is found to play an important role in the success of phage therapies. Since multiple studies suggest that immunity is changed by the spaceflight environment, studying the effect of such changes on phage therapy will further our understanding about the synergistic and antagonistic effects of phages and immune system, and advance phage therapy on Earth.

26. Astropharmacy: Medication management and the pharmacists' role in space exploration

Dr Li Shean Toh - University of Nottingham, UK

Overview

Space tourism and deep space exploration is rapidly advancing. With increased access to space tourism, potential tourists are likely to have different medical conditions and be taking different medicines than fit, trained astronauts. Addressing these challenges will develop solutions that are relevant on earth as well as in space, helping with healthcare in extreme or remote environments, and developing new ways of delivering medication. Pharmacists have an integral role in contemporary healthcare in medication management, dramatically reducing medication-related problems (medication use errors, prescribing errors, adverse effects, therapy failure, poor storage conditions and lack of medication supply). There is limited understanding of the long-term detrimental effects of extreme environments such as microgravity and radiation on the interaction of the human body with medications and medications on board spaceplanes. This means advancing Astropharmacy has huge potential to improve space and terrestrial health.

Related Case Experiences

Astropharmacy researchers at the University of Nottingham are conducting pharmacy practice and policy projects including a project funded by the UK Space Agency aiming to develop pharmacist workforce in space travel to mitigate medication-related problems. Results cite strong support from both the pharmacy and space sector towards research in:

- Medication management for space tourist and deep space travel to understand and mitigate medication-related problems: In order for medication management to be successful, systems and interventions need to be developed to evaluate medication use (therapeutic effects, side effect reporting, near miss reporting, medication reviewing/optimization, medicine use behaviour), ensure safe and continuous medication supply (shelf-life, inventory, quality control, manufacturing, new formulation, stock management).
- Astropharmacy regulatory/licensing board: Funded research at Nottingham working with NASA to 3-D print medication as required in space raises questions about the need for regulations/licensing/policy on-site, on-demand manufacture, be it in space or on Earth.
- Medication research i.e. developing personalized medication, understanding pharmacokinetic, pharmacodynamic, drug-drug-nutrition interaction changes, bed rest studies, utilizing artificial intelligence and developing radioprotective medication.

Impact and Terrestrial Benefit: Driving research and innovation

Solutions developed from these challenges are highly relevant for Earth. Systems, interventions, hardware, manufacturing methods that is feasible for space missions will be useful, perhaps even game-changing, for medical practice in remote terrestrial locations and deployed military or disaster response operations. Methods for shelf-life extension could enhance emergency preparedness stockpiles. Radioprotective medications could provide incalculable benefits for cancer patients receiving radiotherapy.

The University of Nottingham is the UK's leading school of pharmacy and have expertise and interest in Astropharmacy research. We envision the UK to pioneer the world's first Astropharmacy Hub leading in the provision of pharmacy services, regulations/licensing and medication research in space. This one-stop astropharmacy information centre will answer queries from global space travelers, space agencies and commercial companies. If information is needed in space the possibility of an astro-digitalpharmacy to provide remote consultation could be established. The hub would also become a research centre. Pharmacy research in the space sector where relevant can be translated to other terrestrial extreme environments. The Astropharmacy Hub will coordinate pharmacy space activities allowing the UK to take the lead on the first pharmacy space hub crystalizing its position with limitless potential for scientific, economical, and societal impact.

27. ESA Academy

Dr Nigel Savage - HE Space Operations for ESA - European Space Agency, The Netherlands

The European Space Agency (ESA) Education Programme has the objective to inspire and motivate young people to enhance their literacy and competence in science, technology, engineering and mathematics (STEM disciplines), and to pursue a career in these fields in the space domain in particular. To this end, it offers a number of exciting activities that range from training and classroom activities that use space as a teaching and learning context for school teachers and pupils, to real space projects for university students.

The latter activities, enveloped within the ESA Academy, complement academia by fulfilling an all too often missing link between university education and professional experience.

This is achieved through implementation of two approaches. Firstly, by giving teams of students access to unique platforms and competitive opportunities to design build, test and perform experiments or technological demonstrations and secondly, by providing specifically tailored space-related courses in various fields, delivered by industry and agency professional experts.

The first approach, designated "Hands-On Programmes", caters for engineering students as well as scientists who want to gain access to space, or altered gravity platforms. These programmes include "Fly a Rocket!", "Fly Your Satellite!", Rexus/Bexus, "Orbit Your Thesis!", "Fly Your Thesis!", "Drop Your Thesis!", "Spin Your Thesis!" and "Spin Your Thesis! Human Edition". While the "Fly a Rocket!", "Fly Your Satellite!" and Rexus/Bexus programmes are geared toward engineering and non-life sciences, the other programmes (Your Thesis!) give teams access to life-science friendly platforms which include the ISS, parabolic flights, large diameter centrifuges and short-arm human centrifuges.

ESA Academy's second approach to complementing academic training is through the delivery of a series of specialized courses and workshops at ESA Academy's Training and Learning Facility in ESA-Galaxia in Belgium. The delivery of such trainings is performed not only by seasoned academics but also industrial and agency experts with years of experience in the subject taught. A typical course lasts one week on site or 2 weeks if delivered interactively online. Students are set tasks throughout the course and these serve as assessments that can be claimed as ECTS points with the students' universities.

There are currently 20 courses delivered per annum and the topics range from Space Law to Human Space Physiology as well as a variety of space related engineering topics.

Since 2015, 24 students of British citizenship were selected for the "Your Thesis!" programmes which represents approximately 12.5% of students who participate in our life-science favorable programmes. Some of these students formed part of 7 teams spanning 9 UK Universities. Of these 7 teams, 3 performed life science experiments. Interestingly all using centrifuges, investigating the

effects of hypergravity on human skeleton, plasma membrane fluidity and arthritis.

One of these teams, Bristol Bone Biologists from the University of Bristol, successfully applied for "Spin Your Thesis!" in 2018 and set out to investigate cartilage morphogenesis in developing zebrafish embryos in hypergravity. Their findings demonstrated that the growth and morphology of the cartilage and that of muscle remained mostly unaltered in hypergravity. However, altered mechanical properties were identified in jaw cartilage. Indeed, Finite Element Analysis predicted altered strain distribution in certain jaw regions, which upon close investigation revealed local changes in chondrocyte morphology. These findings strongly suggest that gravity influences chondrocyte maturation, which ultimately leads to changes in cartilage structure and function. The two PhD students who initiated this project were also involved in all aspects of project management, from financial dealings with the European Space Agency to outreach events with local school children during science fairs. One of the students remarked, "It's been a fantastic opportunity to work with the European Space Agency Education team and those at the LDC. It's a unique project that has enabled our team to pitch, plan, and run a large-scale experiment from scratch. Collecting exciting data is just one of the great outcomes of the project and we've developed many other management and outreach skills along the way."

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2. <https://www.bristol.ac.uk/news/2018/october/spin-your-thesis.html>

28. Muscle Maintenance, Memory and Space Flight

Prof Claire Stewart - Liverpool John Moore's University, UK

Overview

It is suggested that losses of skeletal muscle mass of ~40% are incompatible with life. Approximately 50% of the healthy adult human body is comprised of skeletal muscle, with any negative impact on muscle mass influencing health. Fortunately, skeletal muscle is highly adaptable, displaying features of both growth and loss. It is well known that space flight culminates in muscle atrophy and models including: head down bed rest and hind limb suspension are providing insight into the impact and mechanisms of microgravity/simulated microgravity on physiological mal/adaptation (reviewed in Prasad, B et al, 2020), including that of skeletal muscle.

The NASA GeneLab project (<https://genelab.nasa.gov/>), enables a systems-based omics approach of research, into the mechanisms of adaptation of biological samples subjected to space travel or to simulated microgravity. Data are curated in the NASA GeneLab repository (<https://genelab-data.ndc.nasa.gov/>). Most data relate to transcription profiling, however, studies of epigenomics and epitranscriptomics are included. Since epigenetic modifications are reversible, mal-adaptations as a result of lifecourse experiences, including space flight, could be reversed.

Related Case Experiences

In the early 2000s, we reported that adult human skeletal muscle stem cells retain a memory of the environment from which they are derived (Foulstone, E et al, 2003). Recently our group (Seaborne, R

et al, 2018) examined the impact of 7 weeks of training (bout1), followed by 7 weeks of detraining and a further 7 weeks of retraining (bout2) on muscle adaptation in healthy, young males. Bout1 resulted in a significant increase in muscle mass, which returned to baseline with detraining. Bout2 culminated in a significant increase in muscle mass compared not only to baseline, but also to bout1. This significant increase in lean mass, as a consequence of the second bout of training, was associated with a doubling in the number of hypomethylated CpG sites, thus facilitating increased gene expression. These data suggest that modifiable epigenetic alterations underpin muscle adaptation.

Impact and Terrestrial Benefit: Driving research and innovation

The NASA resources and developing knowledge around muscle memory provide huge potential not only for astronaut health, but also for reducing atrophy more generally. We know that muscle cells display reduced fibre formation, if exposed to one bout of inflammation, which is significantly worsened when exposed to a second bout (Sharples, A et al, 2015), several weeks later. We also know that muscle mass increases if exposed to one bout of exercise, which is significantly increased if exposed to a second bout several weeks later. Worsened atrophy and improved hypertrophy, respectively were associated with altered epigenetic profiles. These data suggest that the loss of muscle mass as a result of microgravity will be associated with epigenetic changes, culminating in worsened loss, if astronauts are exposed to repeated microgravity. Relevant physiological and functional measures may confirm or refute this hypothesis. Furthermore, analyses of -omics data within the NASA gene lab repository will provide mechanistic insight relating to muscle atrophy. Finally, data from the Rodent Research-1 (RR1) NASA Validation Flight include epigenetic analyses of rodent samples –exposed to spaceflight only once - but providing a first step in our understanding of the role of epigenetics in space-related muscle wasting. Similarly, terrestrials who suffer multiple bouts of disuse or who are highly sedentary, are likely to be most prone to muscle loss. Finally, if multiple bouts of exercise culminate in epigenetic adaptations, associated with enhanced hypertrophy, then this knowledge can be applied to relevant models of atrophy. Exercise interventions that have periods of detraining between bouts of training, might compensate for the losses that are experienced as a result of unloading. To determine the validity (or not) of this hypothesis, initial experiments should compare epigenetic/gene-array/proteome data of space flight vs. resistance training. If genes overlap but are hypermethylated in space flight and hypomethylated in exercise (or vice versa), then the potential to influence muscle wasting exists. There is an opportunity and a need to develop relevant research relating to muscle wasting, in association with International space agencies, with implications not only to space flight and astronaut health, but also to improved healthspan (in line with government objectives) of an ageing and sedentary population.



29. Treatment of Infection and Antimicrobial Resistance

Dr Paul Arkell, Dr Ravi Mehta, Mr Richard Wilson, Prof Tony Cass, Prof Danny O'Hare, Prof Alison Holmes - Centre for Antimicrobial Optimisation, Imperial College London

Overview

Astronauts are at high risk of infection because the environment of space affects both host and pathogen. Natural physical barriers (skin and mucus membranes) are disrupted by injury, drying and chemical irritation, while immune dysfunction occurs with zero-gravity and sleep disturbance. The microbiome of the International Space Station, our longest-term closed space environment, consists of a diverse population of bacteria and fungi, many of which can cause human disease [1]. Bacteria can exhibit abnormal growth characteristics, increased virulence, and even increased antimicrobial resistance (AMR) in space [2].

The diagnosis of infection in space is challenging because obtaining blood (or other clinical specimens) produces biohazardous sharps waste which cannot be disposed-of, and access to laboratory equipment, reagents and expertise in space is limited. Clinical management of an infected astronaut is hampered by accelerated degradation of medications due to environmental stressors such as radiation and microgravity [3]. Profound changes in human physiology impact drug pharmacokinetics (PK) and pharmacodynamics (PD), which may lead to subtherapeutic drug concentrations, drug accumulation, toxicity, poor clinical outcome, and/or the development of AMR [4,5].

Delayed/missed infection diagnosis, combined with the incremental risk of suboptimal treatment, may have catastrophic consequences in space. Therefore, there is a need for research into near-patient detection and differentiation of infection, physiological monitoring, and optimisation of antimicrobial treatment for individuals living in extreme and isolated environments. These technologies will be crucial if humans are to achieve prolonged space travel, such as Mars missions. Moreover their innovation will contribute to better terrestrial infection management.

Researchers in the UK have previously been actively involved in research related to antimicrobial resistance and treatment of infection during space flight. This includes studies of the effect of wearing compression suites on astronauts' microbiome [6] and evaluating rational treatment of infection during space flight [7].

Related Case Experiences

Currently, the terrestrial use of antimicrobials is often suboptimal: treatments are chosen empirically, without rapid diagnostic testing or any prior knowledge of a patient's colonising bacteria, and therefore without full individual assessment of the likely causative organism(s). Drug dosing is determined using aggregate population PK-PD data, and therapeutic drug monitoring (TDM) is sometimes ineffective due to non-standardised drug-level assays, long turn-around-times, and a lack of robust evidence on interpreting results. Changes in infection management are physician-initiated and are rarely supported by integrated artificial intelligence.

Impact and Terrestrial Benefit: Driving research and innovation

Researchers at the Centre for Antimicrobial Optimisation at Imperial College London aim to develop technologies which can optimise the management of infection, improve patient outcomes, and reduce the development of AMR. Our group encompasses research excellence in infectious disease,

data science, artificial intelligence, chemistry, biosensor technology and bioengineering. Areas of development which may directly contribute to space medicine include:

1. The development of novel, rapid diagnostic solutions for the detection of infections and genes associated with antimicrobial resistance at the point-of-care [8,9]
2. The development of clinical decision support systems, which can guide infection management and antimicrobial prescribing, and are aimed at use by non-experts in infectious diseases [10]
3. The real-time minimally-invasive monitoring of antimicrobial levels and biomarkers for treatment response using microneedle biosensors and closed-loop control of drug delivery, as well as capillary (finger-prick) blood sampling [11,12]

There are clear downstream terrestrial benefits of developing these technologies for use in space. For example, they may easily be applied to individuals in other types of extreme environment (expedition medicine, deep-sea exploration, aid work, or conflict). Learning how to optimise infection treatment in these environments will undoubtedly also inform hospital and community treatment in the UK, for example by pushing forward the field of personalised critical care medicine. Furthermore, the process of discovery and mutual sharing of ideas between health and life sciences, bioengineering, and the space sector should provide a nurturing environment for UK-based early career scientists, in order for them to innovate, engage with commercial partners, contribute and compete on the international scientific stage.

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30. Engineering microorganisms for compound production and space exploration

Dr Angeles Hueso-Gil & Dr Rodrigo Ledesma-Amaro - Imperial College London

Overview

One of the main limitations for Space Exploration comes from the expensiveness of putting certain weight in orbit. A proposed solution for this problem is the in situ production of compounds of interest, like fuels, polymers or food supplies for astronauts. We are currently using microorganisms (bacteria and yeast) to produce some of these compounds with commercial value in Earth, and many others are under study for their bioproduction at industrial scale. Therefore, bioproduction has the potential to be exported to other locations out of Earth (1). The efficiency of these processes depends on the optimized function of a set of enzymes encoded in genes. Nevertheless, undesired mutations compromise the genetic stability and effectiveness of designed strains. They severely damage DNA, introduce heterogeneity, lower the production yields and limit microorganisms viability, with subsequent economical losses (2,3). Despite the errors made by polymerases during replication, mutation rate is dramatically increased in the presence of radiation and oxidative stress. Both entangled stresses are usually affecting cultures, but they become more problematic in some particular areas on Earth and extra-terrestrial environments.

Therefore, in situ bioproduction needs a microorganism that can overcome these issues robustly. For that purpose, producer strains (industrial bacteria like *B. subtilis* or *P. putida* and industrial yeasts like *S. cerevisiae* or *Y. lipolytica*; 5,6) should be improved to enhance their stress resistance. This can be done modifying own natural mechanisms or importing new ones from highly resistant microorganism like *Deinococcus radiodurans*, the organism most resistant to radiation known to date. These robust organisms can be further modified to produce compounds relevant for space exploration using waste or abundant space resources as substrates for biotransformation.

Related Case Experiences

Previous works, so far limited to the expression of a single protein from a resistant organism, have identified and characterised some of the mechanisms that reduce radiation or redox impact on

microorganisms (7,8). Importantly, previous NASA programs are destined to elucidate the effects of outer space radiation into different organisms, since overcoming them is key for long space trips, terraforming and colonization. However, it becomes necessary to attempt a deep redesign of an industrial microorganism to build more resistant strains, able to perform their activities in an enduring manner.

Impact and Terrestrial Benefit: Driving research and innovation

The results of this research will benefit both Earth sustainable bioproduction and Space Exploration. In the short term, the advantages of a robust strain will be applied to industrial bioproduction, which will lead to a lower spoilage of cultures and a reduction of economic losses. Bioproduction is usually more sustainable and cleaner process than chemical synthesis. In addition, engineered microorganisms can be designed to use waste materials as substrate and transform them into high-value compounds. This will lead to a circular Bioeconomy or Green Economy, more respectful with the environment. On the other side, in a medium term, generated strains can be used for bioremediation as their higher resistance make them more suitable to keep their functions in hostile environments such as deserted areas. In a longer-term, robust strains can be used in space exploration. Engineered microbes will use either wastes from the spacecraft or resources from the destination place to produce compounds to support human life and settlements, including nutrients, pharmaceuticals or materials for different purposes (1). The utilization of these biotechnological advances represent an important benefit to reduce costs of space missions, as tiny fractions (mgs) of lyophilised cells can be put in orbit in a light and cheap way to be later expanded for their utilization in other locations when needed.

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31. Metabolic physiology and space flight

Prof Ian Macdonald & Prof Paul Greenhaff - University of Nottingham, UK

Overview

When in low-gravity environments, the leg muscles of space crew (which are weight-bearing on Earth) are largely inactive, except when intentionally exercising. Disuse of these large muscle groups results in decreased muscle size, strength and endurance, and has a negative impact on astronauts when exposed to greater gravitational forces, such as when returning to Earth.

Physical inactivity and sedentary time in terrestrial populations affects quality of life, increasing risk of poor metabolic health, functional decline and non-communicable disease development (e.g. type 2 diabetes, hypertension, heart disease) over the life-course. Furthermore, some of the underlying pathologies associated with physical inactivity on Earth (insulin resistance, dyslipidemia, altered fuel metabolism) are also observed in astronauts following time spent in microgravity and could negatively affect their health on longer missions. However, onset rate and magnitude of these pathophysiological responses, whether on Earth or in space, remain unclear.

The similarity between the health effects of muscle disuse experienced by astronauts and those seen in terrestrial populations as a result of physical inactivity creates an opportunity to directly apply scientific knowledge from Earth-based studies to the Space scenario and vice versa.

Notably, UK researchers have contributed to scientific understanding of the physiological effects, and molecular mechanisms underpinning adverse consequences of muscle-unloading in microgravity, which have helped inform developments in exercise countermeasures and nutrition for crew during longer-term space flight.

Related Case Experiences

University of Nottingham (UoN) physiologists have conducted assessments of the metabolic and molecular effects of muscle-unloading of different durations; in humans using Earth-based models of microgravity such as bed-rest and limb immobilisation (including as collaborators in an ESA 60-day bed rest study), and in an animal model (*C.elegans*) after periods residing on the ISS. Moreover, in terrestrial populations, UoN researchers have examined the efficacy of dietary, nutritional supplements and exercise interventions to address the development of non-communicable diseases and their risk factors and are conducting studies to understand the molecular control of skeletal muscle function in health, ageing and disease.

Impact and Terrestrial Benefit: Driving research and innovation

Individuals in the UK are living longer, but increased life expectancy is coupled with greater numbers of those living with non-communicable diseases and disabilities. Alarming, the age that individuals develop these conditions is decreasing and without significant improvements to the health of the population, the future burden on UK health and social systems will increase.

Despite considerable scientific interest in chronic disease development and aging processes, there is still much that is unclear. Conducting longer-term inactivity studies in humans to investigate body systems under controlled conditions (and testing efficacy of countermeasures) is difficult due to requiring specialist residential facilities and high associated running costs. Current space-related research e.g. NASA/ESA bed-rest programmes, provide an opportunity for multiple researchers to concurrently study the body's responses to musculoskeletal-unloading across a range of systems. However, opportunities to access these programmes are extremely limited and there would be merit in developing a UK facility and similar programmes to support the work of National researchers and stakeholders across multiple disciplines.

32. Space health and interdisciplinary practice.

Myles Harris - UCL Institute for Risk and Disaster Reduction (IRDR), UK

Overview

Space medicine focuses on the biomedical (physical) model of health in space and acute medical emergencies; however, astronaut's health needs include minor injury or illness and psycho-social care. The holistic approach to healthcare in space can be described as 'space health'.

Space health brings to the surface many challenges. There are limited resources (human and equipment), a diminishing scope for telemedicine as exploratory space missions venture further into space and no option of a rapid aeromedical evacuation to Earth – the loss of the 'golden-hour' of trauma care (injury to surgery within an hour) on Earth similarly applies to space health. With this in mind, healthcare providers in space are required to have interdisciplinary healthcare practice to be able to meet the holistic care needs of astronauts.

At present, the biomedical foci of space medicine and absence of literature or substantial evidence of space health practice means healthcare providers in space are reliant on their clinical intuition and experience (which may or may not be applicable to space health), heuristically developing space health practice. Thus, astronauts are exposed to clinical practice unsupported by evidence and human error; this is a healthcare system vulnerability and a risk of disaster.

Related Case Experiences

The most closely related active research are being lead by military forces investigating 'prolonged field care' (PFC). The concept of PFC is prehospital healthcare in remote environments with limited resources. However, this research is limited to the context of military healthcare systems, i.e. deployment of small and autonomous units to remote environments. An example is the Royal Centre for Defence Medicine (RCDM) PFC research group.

A PhD research project at UCL IRDR (in collaboration with RCDM) involves researching PFC in the context of remote environments and space. The aim of this research is to systematically develop an evidence-based PFC theory to inform policy and clinical practice. Military and civilian healthcare practitioners, from a variety of related disciplines, are included so the findings are representative of PFC practice with limited resources in remote environments and space. The findings of this research will inform interdisciplinary space health practice and contribute to reducing the risk of disaster in remote environments.

UK Analogue Mission are developing a pilot analogue mission that will investigate interdisciplinary space health within the context of a simulated exploration of an other planetary body. This will be the first empirical study in the UK that investigates interdisciplinary space health practice.

Impact and Terrestrial Benefit: Driving research and innovation

Space health correlates with remote health on Earth. Similarly there is limited access to resources, multidisciplinary healthcare services and rapid aeromedical evacuation. The UN Department of Economic and Social Affairs predict that, despite increasing global urbanisation, approximately 3.1 – 3.3 billion people will be living in a remote environment between the years 2015 and 2050. Health research in the remotest environment of space will produce valuable findings for remote health practice on Earth, contributing to the promotion of resilience and sustainable development for humankind.

33. Harnessing Microgravity as an Accelerated Model for Musculoskeletal Ageing.

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Overview

Shifting demographics are increasingly affecting modern societies, contributing to increasing numbers of older adults with poor health. The mechanistic basis for age-related muscle loss remains unclear, but research has demonstrated that skeletal muscle of older individuals shows maladaptation to exercise, compromising the ability to maintain muscle function. In an analogous but accelerated manner, the muscles of astronauts undergoing spaceflight also rapidly lose mass. Whilst regular bouts of aerobic and resistance training reduce microgravity-induced muscle loss, the preventative effects remain incomplete.

Therefore, there is an impetus to determine whether attenuations of responses to exercise are analogous under both conditions. This will identify opportunities for mitigation strategies, pharmaceutical interventions or technologies to benefit both astronaut health under space-flight and the health and quality of life for older people.

Related Case Experience

The Skeletal Muscle Research group at the University of Liverpool are conducting several studies, with the support of the UK Space Agency (UKSA) and European Space Agency (ESA), to address fundamental questions pertaining to mechanisms of muscle loss under microgravity and how they relate to musculoskeletal ageing on earth.

The MicroAge project, scheduled for launch in November 2021, is a UKSA-funded national mission to the International Space Station (ISS) performed in partnership with Kayser Space Ltd. The study will assess muscle adaptations to contractile activity occurring in tissue-engineered skeletal muscle constructs exposed to microgravity on the ISS.

Changes in mitochondria may underlie the failed adaptations and so loss of muscle. Building upon the foundations of MicroAge, the group are also performing a UKSA-funded feasibility study (MicroAge II), designed to develop approaches to examine how muscle mitochondria change in microgravity and during ageing.

Finally, in collaboration with ESA and the German Aerospace Centre, the research group are exploiting the state-of-the-art FLUMIAS microscope on board the ISS to examine the role of mitochondrial hydrogen peroxide (H₂O₂) as a mediator of rapid muscle loss under microgravity.

Impact and Terrestrial Benefit: Driving Research and Innovation

The UK government's industrial strategy has set out 'healthy ageing' as a Grand Challenge, highlighting the importance of harnessing the power of research and innovation to meet the needs of

our older population whilst achieving 5 more years of healthy ageing by 2035. Microgravity environments and analogues are an important resource for ageing research, providing a platform to examine accelerated ageing phenotypes in skeletal muscle and other major organs. Such research activities have clear terrestrial benefit, extending from fundamental mechanistic studies, through to the identification of druggable targets. Such work will also contribute to alleviating the use of animals in basic laboratory research.

From a space-flight perspective, the Artemis programme is ushering in a new era of space exploration as humanity pushes boundaries, building a long-term presence on the moon by the end of the decade. The Artemis missions will build the foundations for supporting and sustaining life away from earth, as such it is important for us to understand the biological implications of such endeavours so that we may develop effective intervention strategies to preserve astronaut health under microgravity.

34. Surgery, Trauma and Human Spaceflight

Dr James Clark and Dr Rebecca Jones; Academic Surgical Unit (ASU) - Cornwall.

Overview

It is estimated that the cost of training one astronaut is circa £11 million. The requirement to protect such high-value assets is evident, both from the ethical as well as the financial, in order to preserve mission integrity. Although no surgical procedures have been performed on humans during space flight to date, the risk of a problem arising that requires surgical intervention is nonetheless real particularly with further increases in crew size and mission duration projected in the near future for the International Space Station (ISS) and the exploration-class missions that will follow. Moreover, the probability of trauma (including penetrating trauma, lacerations, crush injuries, thermal and electrical burns) occurring will increase as astronauts conduct ISS construction-related extravehicular activities that involve manipulation of high-mass hardware. Routine surgical diseases such as appendicitis and cholecystitis can occur indiscriminately at seemingly random times.

The Military approach to providing emergency medical care to high-value assets employs a tiered system, with a baseline presence of individuals with some medical training as "Role 1", and "Role 2" Damage Control Surgery capabilities being deployed with trained personnel to mitigate the risk to life during periods of high-risk activity. This approach however relies upon a surgical team (which may be as large as an entire space mission crew itself), equipment, and the ability to evacuate the stabilised casualty for definitive treatment, which would present particular challenges for casualties whilst in flight, on the Moon or beyond. This existing model is based upon the open surgery technique, the current standard of care for severely injured patients being operated on in remote locations, which may be less suited to the microgravity environment due to the behaviours of liquids and potential contamination of the vehicle.

The ability to perform surgery during spaceflight will also bring with it the question of when to operate. Deep space exploration missions will have no option for resupply or evacuation, and attempts to save the life of a critically-injured or unwell astronaut could rapidly consume available resources. It may be necessary to abandon treatment in those who do not respond to initial therapy. Any surgical capability must therefore be developed with an ethical framework for its use.

Reflection on previous activity in the field includes:

- 1997 USA; Simulated zero gravity flight; small animals; identification of main surgical challenges.

- 2006 France; Simulated zero-gravity flight, first operation on a human.
- 1992 NASA/DARPA: translational research. Robotic Surgery. One of the largest surgical biotechnology markets globally.
- USA: NEEMO 7 trial; Evaluated surgical telementoring.

Related Case Experiences

The Southwest has strong expertise in space technologies and satellite applications, including Goonhilly Earth Station, Spaceport Cornwall and the Aerohub Enterprise Zone; promoting access to specialist help to remote areas using satellite applications.

Telemedicine has never been more palpable than during the COVID-19 pandemic with work within the ASU-Cornwall into the benefits of Mixed Reality systems.

UK Surgical Robotic companies are challenging the boundaries on the size of their systems; essential for robotics to be part of the solution.

Impact and Terrestrial Benefit: Driving research and innovation

In 2021, the market size of the Biotechnology industry is £75.3bn. The UK has always led globally on innovation in many areas but the key links to support the vast potential for innovation and commercialisation from research within this sector will need fostering.

Innovations which will promote:

1. More efficient global health and military disaster relief support.
2. Improved trauma outcomes through enhanced pre-hospital care.
3. Reduce hospital admissions through remote care.



35. Technology Transfer from Space Medicine to Global Health on Earth

Prof. Thais Russomano, MD, MSc, PhD - CHAPS, King's College London UK & InnovaSpace UK

Overview

Exposure to microgravity affects the entire human body and mind. Astronauts in space for short- or long-term missions have demonstrated important physiological changes, which may lead to undesirable health consequences, requiring clinical evaluation, diagnostic procedures and treatment interventions. Missions often take place without a qualified doctor on board. Consequently, astronauts undergo training to equip them with the necessary skills to identify health problems, collect and transmit medical data to a ground-based doctor, and perform basic medical procedures and treatment.

Important health-related information can be obtained from arterial blood variables, however it is currently not possible to collect arterial blood in the space setting due to potential undesirable complications, such as risk of pain, infection, and hematoma, potential blood contamination of the environment, and the need for a medically certified crew member to perform the procedure. Accordingly, an alternative procedure was developed using arterialized blood collected from the earlobe.

Related Case Experience

An Earlobe Arterialized Blood Collector (EABC) device was developed to standardize blood collection from the earlobe and prevent contamination of the environment. The first EABC prototype, designed in 2000 by researchers at the Microgravity Centre/PUCRS-Brazil, was tested in collaboration with a team from King's College London, and has subsequently undergone modifications and adaptations, leading to 6 versions. Numerous studies have been conducted on the ground, including head-down tilt, hypoxia exposure and exercise, while its operability in microgravity was successfully validated during an ESA parabolic flight campaign in 2006. The basic functionality and operability include earlobe incision, blood collection and blood sample storage for analysis.

Impact and Terrestrial Benefit: Driving research and innovation

Technology transfer from space to terrestrial application is an important consideration for any pioneering technology. Consequently, the EABC was evaluated for use in a clinical context on Earth, with studies funded by the European Space Agency. Research involving hemodialysis and intensive care patients produced motivating results, indicating that the EABC works in different clinical settings and, therefore, could be considered a safe and easy -to-use method for accessing arterialized blood for medical diagnoses, not only in space missions but also on Earth.

The EABC received extensive media recognition, with interviews in magazines, newspapers, podcasts and radio & television programs in European, Asian, and South American countries, and the United States. The EABC was also presented at scientific fairs and featured in an 8-month long exhibition the Science Museum in London, UK, which has more than 3 million visitors a year. These activities aimed to highlight the benefits of Space to Earth technology transfer in the area of global health and biomedical engineering.

Research results suggest the EABC device to be easy to use, safe, low-cost and space proof, enabling the collection of arterialized blood as an alternative to arterial puncture/cannulation, both in the austere environment of space and clinical settings on Earth.

36. Multi-Omics and Space Biology – The Case for Integration in the UK

Dr. Willian Abraham da Silveira - Queen's University Belfast.

Overview

Omics is associated with the analysis of biological big data, with modern high-throughput techniques, to obtain the whole makeup of a given biological function. On November 2020, the largest set of astronaut data and space biology data ever produced were published by journals of the Cell Press. NASA's omics initiative of the Space Biology and Human Research Programme and Twins study formed the foundation of the collection, with one original research paper being the cover of Cell Journal itself. This international collaborative work had an UK university – Queen's University Belfast – in the forefront of the publication.

The work used an integrated analysis of mammalian space biology using a systems biology approach powered by multiple “omic” platforms and reported a widespread alteration related to mitochondrial dysfunction in diverse cell lines, mice tissues and astronauts as a unifying factor for spaceflight biological impact.

Related Case Experiences

Reflection on previous activity in the field (where pertinent/available) include:

- The article “Comprehensive Multi-omics Analysis Reveals Mitochondrial Stress as a Central Biological Hub for Spaceflight Impact” from da Silveira and co-authors, received worldwide coverage from 197 media outlets from 33 countries. It was evaluated to be on the at top 5% of all research outputs scored by Altmetric and including coverage from Forbes, CNN, National Geographic and the UKRI. Showing that Spaceflight Omics research can reach a diverse audience and have a great impact on public opinion on Space research,
- At 2020 the Space Omics Topical Team funded by ESA was co-founded by a UK-based researcher and possess a strong UK component from the University of Exeter, Nottingham, Cambridge, University College London, King's College London and Queen's University Belfast. There is also a strong UK component on the recent funded International Standards for Space Omics Processing (ISSOP) consortium. This put the UK in a strategic position to further develop the future of Space biology research.

Impact and Terrestrial Benefit: Driving research and innovation

Omics is part of a new era of personalized medicine enabled by new technologies. In 2020, 39% of all new drug approval from the FDA were Personalized Medicine treatments. The use of the Space environment in Translational Omics Research can speed up the development of new tests and treatments for Ageing, Mitochondrial Dysfunction, Metabolic diseases as Type 2 Diabetes, Osteoporosis, Muscle Atrophy and many others. This will positively impact our society, increasing the quality of life of the elderly and patients with these conditions, alleviating the pressure on social care systems around the world, increase the number of jobs in the UK Pharmaceutical and Biotechnology market and overall improving UK economy.

The UK already has the infrastructure and know-how to assume a leadership role on Space Omics research in this new dawning Space era. The UK is a world leader in the small satellite industry and it has the potential to use the Genesat-1, a fully-automated CubeSat system for biology experiments, as

inspiration and work to provide a greater access to spaceflight experiments. The UK pharmaceutical industry can use the example of the American Novartis, Eli Lilly and Taconic Biosciences and sponsor missions focused on drug development with the support of the Harwell HealthTec Cluster. The UKRI and the UK Space Agency can, and should, act together to coordinate, fund and plan the strategic biotech development interests of the country. And Academia itself can work to organize itself once a strategy is presented. In all this, Omics Technologies and System Biology approach will be invaluable to guarantee that cutting-edge technologies are being used and bold discoveries are made.

37. Orbital research & manufacturing: how does the supply-chain lead through responsible action?

Charlie Young, Chris Smith, Graham Schultz - Plastron UK

Overview

Commercialisation of space is here with growth across the business continuum, from development of satellite constellations and small launchers to building new spaceports, all stimulating more investment than ever into the sector. Of particular interest is how this influences rapid adaptation of a historically conservative sector – one high in evidence, science and procedural risk-mitigation now transitioning to off-the-shelf technology and agile production where maverick tendencies have to be anticipated.

The prognosis is generally good, with few reservations as the road ahead looks healthy for the industry at large: new space agencies are being established, recognition of sovereign supply-chain and national launch capabilities are acceptable concepts. But low-level alarm bells are ringing, which need addressing even as new legislation is put in place.

'Believing in your own hype' is a sign of when reality is distorting; the space sector must fundamentally avoid this - a sustainable space industry will be underpinned by safety aligned to economic growth. For the sector to succeed, future-proofed regulations, broad capabilities, deep experience and the lessons of a conservative past are required so that economic potential and human/environmental safety will not be compromised ¹.

¹ An evolving trend in disruptive commercialisation is how new entrants are not constrained by convention. This is a significant enabler in many instances. But in high-risk and safety-conscious industries, there must be common ground rules to mitigate risk at a cultural level. By example, as expanding space sectors, both the UK and Australia have tremendous potential in a febrile investment market. But both geographies lack fundamental experience in launch processing safety.

Related Case Experiences

The use of the near-space environment for microgravity-based activities is generating economic opportunities that are destined to grow. But what defines the pragmatic safety regulation required during this period of growth? How can safety and commercial vigour succeed in partnership within this novel environment? What are “safe” limits? How much freedom-to-operate can industry have without compromising safety?

A key step is practicable, self-regulation. The digital industries found this tough, but Space may have the evidence-based cultural rigour to make it work. The premise is simple – willingness to put in protections that can be easily ameliorated through adaptive learning.

In the case of biological and life sciences research, experimental payloads must be controlled and the research observed for both the intended purpose as well as for discovering any unknown/unintended/unexpected side-effects. This needs affordable facilities allowing experiments to be transported and maintained in a quarantined state and prepared under controlled circumstances prior to launch.

Similar facilities must be available for payload return, which is more complex, but must be affordable:

- The payload may still be attached to the orbital vehicle which will need propulsion subsystem decontamination.
- The payload needs to be retained in a quarantined state and suitable environment to avoid bi-directional contamination.

Impact & Terrestrial Benefit: Driving research and innovation

With the UK preparing for orbital and sub-orbital flight in the next 18 months, we need to invest into this arena. NewSpace is happening now and for the UK, we have the potential to lead in this area globally. To do so, our focus must:

- Accept that experimentation and industrialisation in this novel setting will lead to mistakes.
- Establish a baseline for adaptive/iterative learning with balanced regulatory guidance to avoid impractical levels of red tape or risk.
- Establish a regulatory kitemark for safe payload processing across the physical structure, function and skillsets for the supply-chain.
- Develop data-driven system emulators to highlight unintended consequences of orbital experiments; ground-based digital twins can mimic in-orbit experiments, allowing for the prediction and responsive management of unexpected occurrences.



38. Stem cells and biofabrication

Miguel Ferreira, Prof Susan Kimber, Dr Marco Domingos - The University of Manchester

Overview

Biofabrication technologies such as 3D bioprinting are the most promising tools to generate tissue and organ surrogates for medical applications using cells, biomaterials, and biochemical factors. Their combination with human stem cells allows the development of in vitro tissue models able to replicate key features of development and disease which are often absent in animal models or difficult to study in patients, offering great opportunities for research.

Currently, some of the major challenges in the field include:

- Limited self-assembling capacity of cells into tissue constructs;
- Inability to fabricate tissues containing specific architectures or structures such as blood or lymphatic vessels;
- Difficulties in fabrication of complex soft tissues due to the effect of gravity on the shape of soft materials.

Using space as an environment for biofabrication and stem cell research can offer benefits such as:

- Enhanced self-assembling capacity of cells into large tissue constructs due to low or absent gravity. Overcoming issues associated with gravity may allow researchers to print soft tissues with high fidelity, that otherwise would be very difficult or slower on Earth;
- Ability to investigate the effects of spaceflight on the human body using human tissue models. Studies of the effects of gravity and radiation conducted in space using human tissue models can provide important information relevant to human health, while being less reliant on animal models or astronaut studies;
- Potential to create tissue substitutes or cell-based therapies for astronauts in space, which may become important for future long-term missions or settlements on the Moon or Mars. Being far from Earth with limited resources (human and material) will require innovative automated systems for the rapid generation of tissue replacements to provide healthcare solutions in case of accidents or disease.

Related Case Experiences

In recent years, increasing numbers of cell biology and tissue engineering projects have been conducted in space. These include studies of cell behaviour, stem cell differentiation, and bioengineered tissue models such as microfluidic tissue chips. Two bioprinters were sent to the ISS, the 3D BioFabrication Facility (BFF) (1), from the US-based company Techshot, and the Organaut, from the Russian company 3D Bioprinting Solutions (2). These projects are contributing to gain a better understanding on how human cells and tissues behave in space, but also creating new ways to manufacture complex tissues on orbit.

Impact and Terrestrial Benefit: Driving research and innovation

Increased and more widespread access to space and microgravity can accelerate the development of new solutions for biofabrication applications on Earth.

By eliminating the effects of gravity, innovative ways to manufacture living tissues can be developed, such as the use of magnetic levitational bioassembly in the Organaut bioprinter. This may result in new commercial opportunities in the bioprinting field, similarly to what is now being achieved with companies such as LambdaVision (3), which is developing artificial retina technology onboard the ISS for medical applications. In addition, microgravity may also result in unprecedented changes (further to those already recognised) at the cellular level. As well as having medical implications for long-term residence in space, these may generate translatable scientific knowledge towards the development of new therapies for applications on Earth.

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39. Big data in space omics

Dr Pedro Madrigal - Wellcome - MRC Cambridge Stem Cell Institute, Department of Haematology, University of Cambridge, UK

Overview

Until recently, it was known that astronauts suffer bone and muscle loss, a depressed immune response and cardiovascular risk. A series of studies published in 2020 have shown six new molecular changes triggered as a consequence of microgravity, radiation, and isolation in closed environments. These are: DNA damage, oxidative stress, mitochondrial dysregulation, epigenetic changes affecting gene expression, alteration in the length of telomeres, and internal (e.g., human gastrointestinal tract) and external (International Space Station surfaces) microbiome shifts (Afshinnekoo et al, 2020). Some of these changes pose a serious risk to astronaut health, especially in long term missions. For instance, one of the studies have found that Clonal Haematopoiesis of Indeterminate Potential (CHIP) is altered in astronauts, which could accelerate the development of blood malignancies after prolonged stays in space (Trinchant et al, 2020).

Due to the exponential advance of next generation sequencing technologies, its cost reduction, and especially the interest as well as the availability of performing experiments in simulated microgravity conditions or at the ISS, it is now possible to obtain big datasets (transcriptomics, metagenomics, epigenetics, proteomics, etc.) from molecular biology experiments in different organisms, giving rising to the Space Omics subfield in Space Biology research. This emerging field embraces challenges ranging from standardisation of sample processing to computational analysis the data using bioinformatics methods and artificial intelligence to infer new biological insights.

Related Case Experiences:

UK participation in Space Omics consortia: At the European level ESA has funded a Space-Omics Topical Team (TT) to support new and on-going ESA scientific community activities in the field of Space Omics, particularly in the context of collaborative research with NASA and GeneLab Analysis Working Groups (Madrigal et al 2020). The Space-Omics TT includes UK-based researchers from the University of Exeter, King's College London, Queen's University in Belfast, University of Nottingham and the University of Cambridge. The European and UK contribution is also important at the International Standards for Space Omics Processing (ISSOP) international consortium (Rutter et al, 2020). The ISSOP consortium aims to establish sample processing standardization and metadata normalization of spaceflight “omics” experiments.

Impact and Terrestrial Benefit: Driving research and innovation

Benefit of Space Omics and funding recommendations Expected impact of the research is diverse:

- Harmonise international efforts in omics-based space research.
- Accelerate the understanding of many pathologies and diseases, e.g., cancer, cardiovascular dysregulation, central nervous system, immune dysfunction or aging, to name a few.
- Design countermeasures to support life in space: e.g., new applications for aerospace medicine, for instance pharmacological approaches for disease prevention in long-term deep space missions.
- Advances in therapeutics applicable to human health in Earth.

As a consequence of the rising importance of Space Biology, the Aurora programme of the UK Space Agency could include Space Genomics and/or Computational Space Biology research as areas of special interest. The UK Space Agency, responsible for all strategic decisions on the UK civil space, should strengthen collaboration in Life Science research with NASA, ESA and European colleagues, and do not let political barriers imposed by Brexit to affect scientific collaboration.

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40. A flexible miniaturised hardware platform to enable bioscience and biotechnological space science studies

Prof David C. Cullen & Aqeel Shamsul - Cranfield University

Overview

Studying biology in space environments and especially BEO is becoming ever more important to understand the impact of long-duration microgravity and deep space radiation exposure on humans, our human microbiome, associated Earth biology needed to support human activities in space, as well as expected adventitious “ride sharing” biology.

Understanding such impacts is usually unattainable from Earth-based experimentation alone. It is often not accessible nor feasible to replicate long-term microgravity and full spectrum deep space radiation in an Earth-bound research facility. Traditional access to space platforms is limited due to a combination of high-cost, long-lead time and infrequent flight opportunities.

Over the last few years, smaller satellites platforms have reduced entry barriers to access space environments. Nanosats, specifically CubeSats, have democratised access to space enabling many entities to launch their own satellite. The space bioscience field has started to leverage the CubeSat concept to benefit from the lower cost of development and launch. The term bioCubeSat is used to refer to a CubeSat with a biological application on-board. Furthermore, such CubeSat-compatible payloads are being considered as mass and volume efficient standardised payloads suitable for hosting on or in larger spacecraft.

Related Case Experiences

Cranfield University and its partners have been developing a bioCubeSat concept named BAMMsat – an acronym from Bioscience, Astrobiology, Medical, Material Science on CubeSats. It builds upon the common functional requirements associated with a diversity of possible BAMB experiment such as i) the need to house multiple samples, ii) the need to artificially perturb the samples – e.g. via inflight administration of drugs, iii) the need to monitor the samples, and iv) maintain viable samples in an appropriate space environment.

Cranfield University and University of Exeter are currently involved in a technology demonstration of a second-generation design of a BAMMsat payload for flight on a large stratospheric balloon. The demonstration flight is expected in October 2021 from the Swedish arctic. The payload named BAMMsat-on-BEXUS was selected in the REXUS/BEXUS programme realised under the remit of the German Aerospace Centre (DLR), Swedish National Space Agency (SNSA), and European Space Agency (ESA).

The mission aims to perform technology and operation demonstration of the BAMMsat payload in preparation for future spaceflight. The experiment will house live *C. elegans*, nematode worms, in a 2U pressure vessel housing a fluidic system, sensor suite and with active thermal control. The experiment will demonstrate key functionalities of the BAMMsat payload in a representative environment. Stratospheric flight with a varying thermal and near-vacuum environment can be used as a spaceflight analogue. More importantly, the mission helps define and demonstrate the pre-flight operations imposed by biological missions.

Impact and Terrestrial Benefit: Driving research and innovation

The second generation BAMMsat design has 32 independent sample growth chambers and is compatible with a wide range of sample types including microorganisms, plant seeds, mammalian cell and organoid / tissue cultures. It therefore has the capability to be used for a wide variety of future bioscience experimentation.

Given the UK is building an end-to-end space ecosystem from satellite production through launch and operation in orbit and is also an established leader in the bioscience sector, both sectors could combine to help deliver a UK-led increase in innovative bioscience delivery in space – both in LEO and BEO and as free-flying CubeSats as well as hosted on or in large spacecraft.

Benefits of a BAMMsat programme include the support of space-focused activities including (i) delivering basic / fundamental bioscience studies exploiting exposure to space environments, (ii) addressing current unknowns concerning the short and long term effects of space environments on Earth biology and that are needed in support of future long-duration human activities in space, and (iii) for demonstration and de-risking of the use of Earth biology in the technological / operational support of human activities in space – i.e. space biotechnology with examples including atmosphere revitalisation, nutrition production, materials recycling, bulk and fine chemical production, biological ISRU.

For an Earth-based population, further benefits of a BAMMsat programme could include (i) supporting space-enabled pharmaceutical development, (ii) supporting exploration of human tissue engineering in microgravity environments with a long term vision of routine high-value artificial organ growth in space benefiting from removal of weight-driven distortion during growth, and (iii) leverage of BAMMsat knowledge and approaches for Earth-based applications where compact, robust, environmentally controlled, decentralised / remote, flexible and autonomous biomedical, biotechnological and bioscience implementations are required.

Currently, a UK-based start-up – Frontier Space Technologies Ltd. – together with Cranfield University are exploring further developments of, and variants of, BAMMsat for a diverse range of space applications as well as exploring additional partnerships that could focus on immediate non-space / Earth-based applications.



41. Health impacts of sedentariness: Bedrest as a model of space flight.

Dr Raymond Reynolds - University of Birmingham

Overview

Spaceflight has deleterious effects on muscle, bone, cardiovascular and neurological function. Astronauts can take weeks to months to recover their pre-flight strength. Many of these effects can be attributed to the severely reduced energy and strength demands when living in the absence of gravity. Considerable research efforts have gone towards understanding the precise physiological consequences of space flight. One way to mimic the sedentary nature of spaceflight on earth is bedrest. Lying horizontally for a prolonged period removes the need for anti-gravity extensor muscle activity, and reduces the load on the cardiovascular system. Researching the health consequences of spaceflight in this way has profound implications for an increasingly sedentary population on earth.

Related Case Experiences

Researchers from The University of Birmingham have undertaken a bedrest study to understand how balance is affected by prolonged inactivity. This research was undertaken at The Institute for Space Medicine and Physiology, Toulouse (MEDES), and funded collaboratively by The European Space Agency (ESA) and The UK Biotechnology and Biological Sciences Research Council (BBSRC). The purpose of the research was to determine how vestibular control of balance may be affected by bedrest. Vestibular control of balance was studied in 20 Participants immediately before and after 60 days bedrest. This was done using a technique called Galvanic Vestibular Stimulation. The direction of the GVS-evoked sway response became more variable and less accurate following bedrest. This tells us that the brain's ability to detect body motion and convert this into an appropriate corrective sway response is compromised. This could explain why postural control is compromised following spaceflight, or after a long hospital stay for example.

Impact and Terrestrial Benefit: Driving research and innovation

Like most western countries, the UK is currently experiencing an epidemic of sedentariness. Combined with an increasingly aged population, the negative impact on our nations' health is clear. It is therefore important to understand the physiological consequences of sedentary behaviour, and anything that can be done to ameliorate them. ESA-sponsored bedrest studies in Toulouse and Cologne have gone a long way to further this understanding. They are giving us a fuller picture of how muscle, bone and fat metabolism are affected by inactivity. They are also helping us understand why balance is impaired following prolonged inactivity, with obvious implications for fall risk in the elderly population. Apart from revealing the underlying mechanisms, bedrest studies have also investigated possible countermeasures. These include the use of short-arm centrifuges, a variety of strengthening exercises and dietary supplementation. If successful, such countermeasures could readily be applied to the population as a whole. Hence, bedrest is an archetypal example of space research translating into terrestrial benefit.

42. Spaceflight and its application to muscle and ageing

Dr Ross Pollock & Prof Stephen Harridge - King's College London, UK

Overview

The human body is profoundly affected by the microgravity environment with adaption occurring in numerous physiological systems. The musculoskeletal system is highly sensitive to loading and unloading and therefore shows some of the greatest levels of adaption. Without countermeasures, and even with them, muscle atrophy occurs leading to reductions in strength and power. Similarly bone mineral density declines resulting in generally weaker bones. While in space these changes do not pose a significant threat to astronauts. However, the reintroduction of gravity upon return to earth, or to another celestial body, has serious implications for astronauts where even the simplest everyday tasks become challenging. The adaptations observed in astronauts during spaceflight has drawn parallels with those that are typically associated with ageing where reductions in bone and muscular strength and the associated reductions in mobility are common hallmarks of ageing. This has led to the microgravity environment being considered an analogue of ageing, or more accurately disuse/inactivity, which is an area of significant research interest within our group, the Ageing Research at Kings (ARK) consortium and more broadly in the UK and internationally.

Related Case Experiences

Researchers at the Centre for Human and Applied Physiological Sciences at King's College London have recently conducted research using a novel hyperbuoyancy floatation bed to mimic microgravity. This research has utilised a combination of imaging (MRI) and biochemical techniques (creatine (methyl-d3) dilution) to measure changes in total skeletal muscle mass and in neuromuscular function. Microgravity analogue research of this nature will help us develop our understanding of how the space environment and unloading influences the neuromuscular and skeletal systems. This will also help identification and development of optimal strategies to mitigate the effects spaceflight has on these systems. It complements our broader ageing research themes regarding the study of healthy ageing using highly active individuals and with previous research on exercise countermeasure aids including work on the MIT SkinSuit.

Impact and Terrestrial Benefit: Driving research and innovation

Research of this nature has implications not only for astronauts but also could be beneficial for older individuals. A primary limitation of ageing research is that it is predominantly cross-sectional in nature making its interpretation difficult due to the presence of numerous confounding variables. This can be overcome by conducting longitudinal studies, however, these take a number of years, are time consuming and logistically challenging. The adaptations that occur in microgravity and bed-rest studies (or similar) mimic the deconditioning that accompanies ageing but in a significantly accelerated manner. As such they can be used as a model to study age-associated frailty or loss of intrinsic functional capacity, but also disuse-associated reductions in metabolic health that accompany inactivity which can lead to conditions such as Type 2 diabetes. These are major areas of interest terrestrially due to our ageing population and the rise in activity-related diseases. These have significant impact on the health and wellbeing of individuals, health-care systems as well as socio-economically. Research on the impacts of (simulated) microgravity thus has direct benefit not only for astronauts but also for populations on earth.

43. Human factors in crewed spaceflight

Dr Richard Skipworth - Royal Infirmary of Edinburgh/University of Edinburgh

Overview

Medicine has learnt many lessons from the aviation and space industries regarding the importance of human factors to patient safety within high-risk environments (e.g. operating theatre, intensive care unit). A major area of development in surgical specialties has been the recognition of non-technical skill acquisition, by both the individual surgeon and the whole surgical team, as a key determinant of patient safety and successful surgical outcomes. This is an active area of research globally, epitomised by the rapid and effective uptake of the WHO surgical checklist as developed by Atul Gawande. There remain significant unexploited opportunities for cross-pollination of human factors research between the aerospace industry, space medicine, terrestrial medicine, and both astronaut mission/patient safety.

Reflection on previous activity in the field (where pertinent/available) include:

- Researchers at the University of Edinburgh represent one of the key leading international research teams in human factors in healthcare, especially surgery. This research has been supported by a new Chair of Behavioural Science (Prof Steve Yule) in the department of Clinical Surgery. Prof Yule was instrumental in the development of the NoTTS (Non-Technical Skills in Surgery) taxonomy and training courses supported by the Royal College of Surgeons of Edinburgh.
- Prof Yule's previous appointment was with Harvard University and the STRATUS Center for Medical Simulation at Brigham and Women's Hospital. His research (past and present) involves regular collaboration with NASA, involving simulation and team-based projects around medical event management for future deep space exploration missions to Mars.

Related Case Experiences

A current research project involving researchers at the University of Edinburgh and Harvard University involves an international, multidisciplinary expert panel compiled to establish the feasibility and development of a mixed reality (MR, including virtual reality and augmented reality) care-delivery guidance system to support medical event management on long duration spaceflight missions. This research project is funded by NASA - Translational Research Institute for Space Health (TRISH).

Impact and Terrestrial Benefit: Driving research and innovation

The potential impact of a wider understanding of aerospace-derived human factors to terrestrial medicine is enormous with opportunities for improvement to both individual patient outcomes and overall healthcare systems. Equally, the innovative potential for projects investigating the interface between humans, wearable technology, and non-human agents (e.g. AI) is significant and bidirectional (important to both terrestrial and aerospace industries). For example, with regards to the project detailed above, the envisaged result will be the inception of novel and innovative MR technology, to provide safe development of both long duration space missions and terrestrial telemedicine, particularly with regards to rural and austere environments. However, without easy access to UK collaborators and space agencies in this field, at present, the previously described projects are being performed with US counterparts. The development of such research programmes within the UK would also lend themselves to the implementation of a UK version of TRISH.

44. Educational opportunities for bioscience students in experiment development for International Space Station science payloads.

Daniel Molland^{1,2,3}, Zoe Gaffen^{3,4} & Dr Julie Keeble^{2,3}

1. Department of Biochemistry, King's College London, London, UK

2. Centre for Human & Applied Physiological Sciences, King's College London, London, UK

3. International Space School Educational Trust

4. Multidisciplinary Teaching Laboratories, King's College London, London, UK

Overview

The cost of sending an experiment to the International Space Station (ISS) has historically prevented any but the most well-funded of UK laboratories from sending bioscience experiments to space. Simplified design and reduced costs to launch has initiated a revolution that now enables significantly enhanced access to space for bioscience students in the UK. Within the Centre for Human & Applied Physiological Sciences at King's College London, the Keeble research group offers a unique opportunity for undergraduates to develop experiments for launch to the ISS. The experiments the students develop cover a range of research disciplines ranging from protein activity studies to applied physiology on small organisms such as Daphnia or earthworms. By exposing undergraduate students to the challenges and rewards of developing experiments for spaceflight this group acts to empower the young scientists who will be central to the UK's long-term ambitions in space.

Related Case Experiences

Behind the experiments developed within this group is the International Space School Educational Trust (ISSET), of which Dr Keeble is the Chief Scientist. This Trust provides educational experiences (the Mission Discovery programme) for students aged 14-18 to produce ideas for scientific experiments for launch to the ISS. The students are supported by a range of NASA astronauts and engineers alongside university scientists. The winning ideas that these students produce are fed into the Keeble group which are then developed by undergraduate students into fully functional experiments that are launched to the ISS. This scheme has so far produced over 30 experiments, launched aboard 8 separate commercial resupply missions. For undergraduate bachelor or masters students, the development of these experiments provides an unparalleled educational opportunity. In this context, university students learn how to develop a study that best delivers on the proposals produced from the Mission Discovery programme. These students learn how to balance the constraints of performing an experiment in microgravity while maximising scientific benefit. Examples of these are; fluid management, maintenance of microorganismal health during spaceflight and experimental durability management. The diverse range of topics that undergraduate students can develop in this group provides an extremely multidisciplinary setting for students to discover how the biosciences can be applied to problems of human health and biology in space.

Impact and Terrestrial Benefit: Driving research and innovation

With future Mars missions a decade or more away, the bioscientists who will be facing the biological

challenges of this feat, are the undergraduates of today. By providing a feasible method of access for undergraduate students to work with projects that are sent to space, the Keeble group empowers and equips students with the knowledge and technical expertise required to handle biological spaceflight experiments. The increased accessibility of performing experiments aboard the ISS places a need on other educational institutions to provide this level of training to undergraduates. This will ensure that the UK educational sector can offer the calibre of scientists required to meet the bioscientific challenges that further Lunar and Martian exploration will bring.

45. Bubbles in space

Dr. Li Shen - Imperial College London

Overview

We see bubbles in everyday life, yet we still don't fully understand the mechanisms for their rupture. The transient and fragile nature of the interfacial fluid dynamical instabilities on the bubble are both fascinating and fiendishly difficult to study. On Earth, gravity drains the bubble film which causes it to eventually collapse. Without gravity, pure water bubbles can often sustain itself for a very long time. Amongst other things, the ability to take out gravity from the equation allows detailed analysis of how surface-active agents (surfactants) or biological contaminants transport on the liquid interface and the bubble. This surface transport process is particularly of interest in understanding the mechanisms that a liquid interface becomes contaminated and how this contamination affects the stability of the liquid film itself.

Reflection on previous activity in the field include:

- Researchers from the UK have been very involved in studies of the interfacial dynamics and surface transport of liquid films in the presence of surfactants and (biological) contaminants.
- Previous work conducted by researchers in the UK has contributed to advancing the knowledge of contaminated interfaces, leading to optimisations of the foaming processes and bubble-based drug delivery mechanisms. There is evidence that the findings on interfacial contamination being directly applicable to biomedical applications whereby surfaces can be contaminated, recently the research from Imperial College London derived insights on the spread of covid-19 in air droplets in the current pandemic.

Related Case Experiences

Researchers at Imperial College London and Brunel University London are currently conducting several projects on the surface transport of contaminants using both continuum and molecular dynamical methods. This includes looking at how surfactants and biological contaminants transport on the liquid interface, including the unentangling of the effects of gravity on the entire system. This project will reveal fundamental insights into how a liquid surface can become contaminated enough to alter its dynamics.

Impact and Terrestrial Benefit: Driving research and innovation

We have an active community of thin-film fluid dynamicists in the UK (see the UK Fluids Network), with the potential to contribute to space-related science projects. Bubbles and foam experiments are ideal candidates for experiments in microgravity conditions both due to its simplicity to set up and also the considerable amount of insight that could be gained with even the simplest of experiments.

In terms of downstream terrestrial benefit of work being conducted by UK Fluid dynamicists focused on microgravity surface fluidics, there is very clear links that the understanding of surface contamination will be beneficial from both a scientific point of view of being able to understand why a bubble film changes its rupture behaviour; to industrial applications such as the precise optimisation of the foaming process in the beverage and the fuels industry; to even policy planning in events of a pandemic.

46. Radiation Biology and Space

Prof. Giuseppe Schettino^{1,2}

¹National Physical Laboratory, Medical Marine & Nuclear, UK

²University of Surrey, Department of Physics, UK

Overview

The radiation conditions within the space environment present significant challenges, the effects of which need to be accurately evaluated and considered in the planning of space missions particularly in outer space (i.e. Mars missions, away from the shielding effect of the earth's geomagnetic field). Radiation Biology is a multidisciplinary field aiming to understand the mechanisms underpinning the effects of radiation on biological samples. This is a critical aspect of ensuring the safe and optimal use of radiation in clinical practice (many diagnostic and therapeutic modalities use ionizing radiation) and quantifying risks for the population (due to background levels as well as occupational exposures and accidents).

There are a number of features of the radiation environment in space for which radiation biology research on earth would be beneficial, and vice-versa space irradiation would provide a unique source of data for terrestrial applications. Specifically, cosmic radiation is predominantly made of energetic charged particles which are now being considered for cancer treatment (radiotherapy). Moreover, astronauts are exposed to an average level of radiation for which there is little or no epidemiological data or established radiation risk models. Finally, the nature of the cosmic radiation is such that only a small number of cells in the body will receive a large radiation dose, presenting unique radiobiological challenges.

Related Case Experiences

Prof. Schettino and NPL have a long-standing and significant research interest in the response of cells and tissues to ionizing radiation, with the aim to evaluate the effects on the human population and improve clinical practice. This includes the design and development of unique radiation facilities (e.g., microbeams) able to deliver an exact pre-selected number of charged particles to specific sub-cellular targets and assess the cellular responses. This both helps in optimizing the adoption of protons and heavy ions in cancer treatment (hadron-therapy), and it mimics in a controlled manner the unique radiation pattern to which astronaut cells are exposed. Over the years, microbeam data has been used by NASA to refine radiation risk models for astronauts and estimate the radiation risk for space missions.

Impact and Terrestrial Benefit: Driving research and innovation

Astronauts represent a well-controlled population sample to assess the effects of radiation exposures which cannot easily be reproduced on earth. Observation of the long-term consequences

of the exposure to energetic heavy ions would provide valuable information for the planning of future radiotherapy treatments; helping to evaluate their tumour cell killing effectiveness as well as secondary cancer induction and neurological risks. Similarly, the data being collected from cancer patients undergoing proton/hadron-therapy could be used for determining the maximum length of space missions and the related shielding requirements (including chemical agents for radiation protection and DNA repair stimulation). This would be essential for prolonged space missions and the establishment of lunar and Mars settlements. More generally, there is a strong need for validation and improvement of radiation risk models in relation to phenomena such as the bystander effect and the relevance of the stochastic nature of radiation damage to the DNA to be fully elucidated. A closer collaboration between the radiation biology research programmes and the international space agencies would provide unique research opportunities and stimulate the radiobiological developments (e.g. effects of microgravity on cell repair processes) for the benefits of both communities.

47. Decision-Making beyond our orbit: the psychological process of navigating uncertainty and stress

Prof. Laurence Alison & Dr Neil Shortland - University of Liverpool

Overview

Critical incidents are defined by high stakes (commercial, physical, psychological), uncertainty (about the task and / or the outcome), accountability (blame) and uniqueness (rarely or never before encountered). The complexity of dealing with them is exacerbated when they are fast moving, with multiple conflicting pieces of information and when demands outstrip resources (people, equipment, logistic support). Under extreme levels of physiological and psychological strain, astronauts facing critical off-nominal incidents in space have to wrestle with uncertainty, complexity, time pressure and accountability in order to operate within a set of strategic, mechanical and ethical boundaries. Navigating such situations is an immensely complicated cognitive process and requires effective and timely decision-making. When this decision making is impaired and/or selections have to be made based on least-worst options, this can lead to redundant deliberations (not wanting to make any decision).

Related Case Experience

Over the past several years, our project team (Alison, Shortland) has established a track record of studying high-uncertainty decisions that involve juggling between unappealing and potentially negative outcomes in soldiers (Shortland & Alison, 2020; Shortland et al., 2020a), police officers (Alison et al., 2013a; Shortland et al., 2020b) and wider critical incidents (Alison et al., 2013b, Alison et al., 2015, Alison et al., 2017). This research could easily be applied to the similarly demanding context faced by astronauts. In particular this work would provide insight to safety-critical operations in space that may differentiate between mission success and failure.

Impact and Terrestrial Benefit: Driving research and innovation

Clearly, this work has direct relevance to space safety and human performance. There are also broader terrestrial applications for understanding critical incident decision making in high pressure situations like in space. Increasingly psychologists are beginning to focus on the importance of being

able to overcome uncertainty and act before it is too late. Throughout 2020 the response to the COVID-19 pandemic was hindered by delays in decisions and the inability of decision-makers at all levels to commit to "least-worst" choices. At the time of writing (January, 2021), the importance of understanding the decision-making that occurs in these kinds of high-uncertainty situations cannot be underestimated. During 2020-2021, we have seen the aftermath of the several isolated incidents of police decision-making result in worldwide protests. Now more than ever we are beginning to understand the immense importance of studying how people make decisions under uncertainty and the universal negative implications of decision inertia and negative decision outcomes.

With the right funding and partnership working to enable US-UK collaboration, this work initially situated around military and police decision-making, could be applied to address open scientific questions relevant to international space agencies and other partners.

By doing this work we can not only deepen our understanding of the roles of strain and uncertainty in extremis on decision-making, which will support our understanding of the unique challenges faced by astronauts, but also develop general theories of decision-making which can be used in a range of domains on Earth, from the medical field to the financial districts and anything in between.

48. Understanding the effects of (altered) gravity on cognition to advance human spaceflight

Dr Elisa Raffaella Ferre - Royal Holloway University of London

Overview

Human spaceflight has gained traction over the past decades: manned missions to Mars and commercial spaceflight are no longer in the far distant future. Since the first space missions, however, it has been clear that exposure to altered gravity leads to dramatic structural and functional changes in the human physiology, including alterations in the cardiovascular, neural and musculoskeletal systems^{1,2}. Space is hostile to human life and the upcoming exploration missions will present much greater challenges to human health and performance than the challenges currently faced. Unprecedented distance, duration, isolation and increasingly autonomous operations will be combined with prolonged exposure to altered gravities. With an eye towards deep space human missions and space tourism, it is a pressing research goal to get a better insight into how altered gravity influences human behaviour and performance.

Gravity has been constant throughout the ~4 billion years of terrestrial evolution and all organisms have perfectly adapted themselves to it. Gravity is the most persistent sensory signal in the human brain, however little is known about how gravity shapes behaviour. On Earth, when the head moves with respect to gravity, the vestibular otoliths - sophisticated receptors in the inner ear - shift with the direction of gravitational acceleration and signal to the brain the direction and magnitude of gravity. Thus, when the vestibular system works efficiently, the pull of gravity generates a constant sensory flow from early foetal life until death. Studies have shown that changes in the central nervous system occur during and after spaceflight in the form of neurovestibular problems. In altered gravity, signals from the vestibular system become misleading and trigger a neurovestibular conflict which affects processing in different brain areas. Spatial disorientation^{3,4}, perceptual illusions^{5,6}, balance disorders⁷, motion sickness and altered sensorimotor control⁸⁻¹⁰ have also been reported by astronauts during spaceflight.

Related Case Experiences

Researchers at the Royal Holloway University of London are currently conducting vestibular neuroscience projects supported by national and international bodies, including ESA and ELGRA. This include research on the effects of altered gravity on the human brain and behaviour. For example, we have recently demonstrated sub-optimal decision-making in lab-simulated altered gravity conditions¹¹. That is, people were less prone to generating novel and adaptive behaviours in conditions typical of spaceflight. This suggests that deep space astronauts and space tourists may benefit from some sort of cognitive enhancement training or in-flight countermeasures to help in overcoming the effects of altered gravity on the brain.

Impact and Terrestrial Benefit: Driving research and innovation

Despite the advancements and investments in space technology, the human factor has been so far slightly neglected in spaceflight. Focus has been given to medical support for different physiological systems, such as spine and muscles. A pressing issue is the lack of effective countermeasures for mitigating the effects of altered gravity on brain and cognition. Understating how gravity influence brain and behaviour is crucial to assure successful and safe manned space missions. The benefits for society are straightforward. Any rigorous scientific work that moves towards the improvement of human performance in spaceflight will have a major impact on the space industry in terms of training, in-flight operations and medical system support. The knowledge gained by our research might impact clinical patients. Patients affected by vestibular disorders, including Ménière's disease, report motion sickness and vertigo as the most common and compelling symptom. However, perceptual, cognitive and affective alterations have been frequently observed. To date, no effective treatment has been found to alleviate these symptoms and our results could also be very relevant to improve patients quality of life.

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49. Investigating the effects of micro- and hypo-gravity on lumbopelvic musculoskeletal deconditioning and postural control

Prof Nick Caplan and Dr Enrico De Martino - Northumbria University

Overview

Exposure to the microgravity environment leads to significant musculoskeletal deconditioning, a complex process of physiological change following a period of reduced physical activity. Musculoskeletal deconditioning leads to injury risk and physical disability on return to the +1Gz loading environment of Earth, and could pose a threat to astronaut health, operational effectiveness and mission success in other +Gz loading environments that astronauts will have to work in on other planetary surfaces (e.g. the Moon or Mars). Since the dawn of human spaceflight, astronauts have engaged in some form of exercise whilst on orbit to try to prevent, or mitigate, these deleterious effects. For many areas of the body, in-flight exercise countermeasures have been relatively successful. For the spinal column and lumbopelvic muscles, however, astronauts still return to Earth from the International Space Station (ISS) with notable deconditioning, requiring intense rehabilitation to return them towards a pre-mission state.

Related Case Experiences

Since 2009, researchers from the Aerospace Medicine and Rehabilitation Laboratory at Northumbria University have investigated the role of reduced (hypo-) gravity on lumbopelvic deconditioning, a pre-clinical condition characterized by structural change of the spinal column (loss of physiological spinal curvatures) and decline in function of the lumbopelvic muscle. The researchers completed a number of operational evaluations of a potential tool for post-mission lumbopelvic rehabilitation called the Functional Re-adaptive Exercise Device (FRED), sponsored by the ESA Space Medicine Team^{1, 2}. This work, involving collaborations with the ESA Space Medicine Team, Oxford University and world leading experts in low back pain and spinal health from Australia, recently led to FRED being trialled in the ESA/NASA Artificial Gravity Bedrest (AGBRESA) campaign in 2019, with this study funded by the UK Space Agency (via the Science and Technology Facilities Council) as a potential rehabilitation intervention.

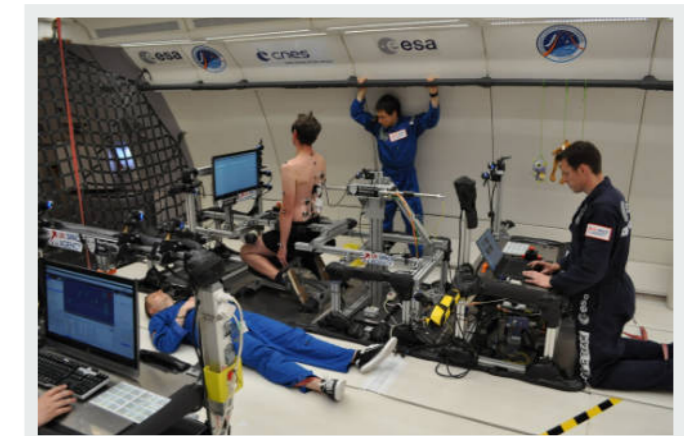


Figure 1. The Northumbria University research team on the 1st Inter-agency parabolic flight campaign 2018

Also, during the AGBRESA campaign, the team investigated the potential role that daily exposure to artificial gravity (AG) has in the maintenance of lumbopelvic muscle size and neuromuscular function using MRI, intramuscular electromyography and balance assessment. It was found that 30 minutes per day of AG was insufficient to mitigate the negative impact of microgravity on lumbopelvic muscle size³, but balance impairments were smaller in participants exposed to intermittent AG⁴.

Also funded by the UK Space Agency (via STFC), the Northumbria University researchers investigated the role of hypo-gravity on spinal postural control, using 3D motion capture and intramuscular

measurements of spinal muscle activity on parabolic flights during the 1st Inter-Agency Partial Gravity Parabolic Flight Campaign in 2018, to help understand how the human body might be affected when we venture beyond low Earth orbit to the Moon or Mars. This study examined spinal posture and postural control in 0.25g, 0.5g and 0.75g, finding that the reduced gravity environment resulted in less movement of the spine in response to a perturbation applied to the spine, with this reduced movement also associated with reduced activity of the paraspinal muscles but increased activity of the abdominal muscles ⁵.

Impact and Terrestrial Benefit: Driving research and innovation

Physical inactivity is estimated to cost the UK £7.4billion each year, including an approximately £1million cost to the NHS. Musculoskeletal injuries caused 27.8 million days lost in work in 2018, second only to minor illnesses (e.g. coughs and colds) ^{6, 7}. The lumbar spine, specifically, is one of the most sensitive musculoskeletal regions affected by physical inactivity or sedentarism.

Micro- and hypo-gravity environments, either actual (e.g. ISS) or simulated (e.g. bedrest) provide unique environments in which to explore lumbopelvic deconditioning in an accelerated way, measuring adaptations that might take many years on Earth in a matter of weeks/months. Participants are healthy, so research findings are not confounded by other injuries or diseases that many patients on Earth present with. Uniquely, it is possible to use a pre-post research design, where data can be obtained before any deconditioning has taken place (i.e. pre-disease/injury state) – this is not feasible to do in terrestrial populations.

The work being conducted at Northumbria University, specifically, will help the development of effective interventions for lumbopelvic health, both in-flight and post-flight for astronauts, and also for people at risk of, of that have already developed, lumbopelvic deconditioning on Earth.

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50. Agri-tech development for human space habitats

Dr Giovanni Sena - Imperial College London

Overview

Prolonged human missions in space, whether in Earth orbit, interplanetary travel or future planetary colonies, will require access to a stable and abundant food supply. Since it would be impractical and economically prohibitive to carry the required amount of food from Earth, the supply will have to be produced on-site. The most obvious solution is to grow crops.

Although small plants have been shown to germinate and grow on the International Space Station (ISS) in Earth orbit, large-scale and sustainable agriculture in microgravity (μg) conditions still needs to be developed. Besides the delivery of light, water and nutrients to the plants, one of the main challenges is in the development of soil-less cultivation systems which would work in μg . Again, it would be incredibly expensive to carry natural soil from Earth, so alternative solutions need to be found. Some soil-less cultivation methods (e.g. hydroponics, aeroponics, aquaponics) have been developed to work in standard 1g gravity. Unfortunately, the translation of such technologies to large scale operation in μg is not trivial and requires more R&D.

Moreover, many aspects of plant biology in μg are still unknown. For example, the development of complex branched root systems in absence of the gravitational stimulus (sensed by roots) is not fully understood. This is crucial for an efficient interface between the plant and the substrate containing water and essential micro-nutrients.

To significantly advance the development of sustainable agriculture in space, in the next decade it will be necessary to fund research programs to study plant biology in μg , as well as to develop new technologies to support long-term cultivations of crops in soil-less and μg environments.

Related Case Experiences

Researchers at Imperial College London are currently developing 3D-printed, hydrogel-based, support systems to grow plant roots in soil-less and μg conditions. The ultimate goal is to control the development and branching of the root system even in absence of gravity, to allow larger crop plants to stay anchored while absorbing water and nutrient from the soil-less substrate.

The next step of this project will be to collaborate with ESA or NASA to gain access to the ISS and test the system in μg .

Impact and Terrestrial Benefit: Driving research and innovation

The development of soil-less cultivation methods has the potential not just to allow extended human space exploration, but also to revolutionize agriculture on Earth. Crop cultivation currently requires large amounts of two of the most precious resources on Earth: fresh water and land. Any solution to minimize either of them would make a significant impact in supporting sustainable agriculture for the future. The recent direction towards vertical farming is certainly a step in the right direction, but new bold ideas and funding programs are necessary to push research and innovation in agri-tech even further and to reduce land use at a significantly larger scale.

51. Space & Architecture – Architecture & Space: A Rare Reciprocal Relationship

Prof. Marjan Colletti - The Bartlett, University College London, UK

Overview

Space and architecture are inextricably linked. Space (1.0, terrestrial) is a fundamental constituent, and goal, of architecture – a long-established discipline that has an inherent and thorough understanding of human inhabitation on this planet. Architecture is equally paramount to space (2.0, extra-terrestrial) as humans cannot live and survive off-world without an adequately designed environment. In a rare and reciprocal relationship, they can tremendously influence and advance each other.

Downstream contributions: space delivers knowhow, technological innovation and progress for P2P comms, for agile, responsive, performative materials and building systems (micro scale); system autonomy and clean renewable energy (meso scale); in EOS (Earth Observation from Space) and PNT (Position, Navigation and Timing) data for smarter cities (macro scale). Upstream, architecture provides expertise in designing, building, delivering and maintaining responsive building components/systems, rapid-prototypeable material systems and robotic fabrication strategies (micro); providing orbital/planetary, non-gravitational/gravitational, scientific/touristic ground/space system designs; advising on psychological issues related to spatial constraints, remoteness, isolation, homesickness, self-reliance, training; educating astronauts on on-site co-living policies and social inclusion (meso); outlining and advising on space policies, including new approaches to organisational networking and international collaboration (macro). Once a highly sophisticated machine turns into a home – even an emblem of human civilisation – paradigms shift from technical, rational and scientific parameters towards soft skills and the unquantifiable variables of intuition. Architects then provide expertise on non-gravitational experience (micro), design VR/AR/XR environments to transcend physical and emotional constraints (meso) and educate on cultural aspects of extra-terrestrial colonisation (macro).

Related Case Experiences

Researchers and students at Master and PhD level at The Bartlett UCL are currently elaborating terrestrial, lunar, cislunar and Martian architectural projects based on smart material systems, robotically bio-tech rapid-prototypeable fabrication systems, non-gravitational settings and smart city strategies. In collaboration with UCL Space Domain, the Sir Lawrence Wackett Centre at RMIT, the Astronautical Engineering Department at USC, national and international partners from academia and practice (e.g. offices like Foster + Partners, Zaha Hadid Architects, Hassell Studio, BIG-Bjarke Ingels Group etc.), the American Institute of Aeronautics and Astronautics (AIAA), the Moon Village Association (MVA), the International Lunar Exploration Working Group (ILEWG), with space agencies (ESA) and hi-tech industries, a series of design-focussed events and workshops are being proposed, commencing at the Venice Architecture Biennale 2021.

Impact and Terrestrial Benefit: Driving research and innovation

Currently, there are limited platforms to support architects to apply their expertise to space. Funding is necessary to initiate blue-sky initiatives and micro, meso and macro scaled projects to nurture the space-architecture-space rare reciprocal relationship.

I am developing a research program on human space activity with fellow professors of Architecture at USC (Madhu Thangavelu) and RMIT (Tom Kovac) to bring together architecture, industrial design,

fashion design with social sciences, health and life sciences and engineering. The envisioned trans-disciplinary research centre seeks to developing new knowledge, reimagining the future of space programs and bringing a greater understanding and design responses and solutions for human life on Earth.

52. Microbiology in support of space exploration, ISRU, and terrestrial life sciences challenges

Charles Cockell¹ and Rosa Santomartino¹

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Overview

Microorganisms carry out a vast range of industrial processes from biomining to drug and food production. In addition to their beneficial roles, they are also responsible for fouling pipes, degrading plastics and metals, processes which have been observed on space stations as well as on Earth. Microbes are also fundamental to human health. However, the effects of space flight conditions on microbial growth, including altered gravity and radiation regimens, are still poorly understood. Knowledge of how microbes respond to space conditions will enable us to use them more effectively to carry out processes such as producing oxygen in life support systems or extracting useful minerals and elements from regolith and other planetary materials, and control their deleterious effects. By investigating how microbes grow under space conditions, we gain fundamental insights of benefit to applied microbiology on Earth.

Related Case Experiences

Researchers at the University of Edinburgh flew the ESA BioRock experiment, the first experiment to demonstrate biological mining of economically useful elements (rare earth elements and vanadium) in space (under microgravity and simulated Mars gravity) on ISS. Continuing that collaboration with Kayser Space, the group flew the first commercial science experiment (BioAsteroid) from the UK to ISS to study interactions of microbes with rocks under the BioReactor Express programme. These experiments led to the development of a new bioreactor that can be used to carry out cell growth experiments of any kind in space.

Impact and Terrestrial Benefit: Driving research and innovation

Microorganisms are involved in countless industrial processes including biomining – extracting economic elements from rocks. About 20% of the world's copper and gold, for instance, is extracted from rocks in biomining. This capability is underpinned by a fundamental understanding of how microbes grow, form biofilms, and carry out chemical processes, information which also has application in food and drug production, biodeterioration of materials and understanding microbially-caused diseases. To be able to understand how microbes grow and carry out such processes, we need to know how the environment around them affects growth. Space offers the opportunity to investigate how gravity, fluid dynamics, radiation, and other factors, influence growth. In the longer-term, these experiments enable us to determine how to use microbes in ISRU, for example to process rocks into soil and how to use local regolith in life support systems. All these data allow us to better understand the uses of microorganisms on Earth.

The BioROCK and BioAsteroid experiments have led to collaborations with Kayser Italia and Kayser Space over ten years with support from STFC to develop an entirely new cell growth chamber that can be used in space biology experiments. The apparatus is currently being augmented for automation in locations such as the Moon. New innovations in biomining (including a paper in Nature Communications reporting the first biological mining experiment in space) have been published as well as papers reporting novel findings on the role of gravity in influencing microbial growth. These experiments, and future ones like them, enable the UK to take a leading role in space life sciences for the future exploration of the Moon and other locations and derive its Earth based benefits.

53. Investigating the role of axial loading (gravity) upon intervertebral discs

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Overview

Exposure to microgravity is associated with multi-system deconditioning despite the performance of daily exercise. In addition, despite periodic axial loading induced during such exercise (Green & Scott, 2018) microgravity is associated with stature increments of up to seven cm's, back pain and an increased risk of intervertebral disc (IVD) herniation and other pathological signs post-flight. These present a potential risk to the health and functionality of astronauts, and their mission. Despite this, little is known about the pathophysiology of spinal changes and the suitability of countermeasures to mitigate such problems.

Related Case Experiences

Since 2009, King's College London has been evaluating axial-loading, via elasticated garments as a potential countermeasure. Having updated and evaluated the Gravity Loading Countermeasures SkinSuit (GLCS) prototypes from MIT, it was found providing axial loading sufficient to 'replace' 1g was poorly tolerated (Attias et al., 2017; Carvil et al., 2017). However, building upon work from MIT and RMIT universities, King's in partnership with ESA and Dianese, adapted the principle to develop the SkinSuit. This focusses on providing a graduated axial-load, similar in magnitude to a back pack (i.e. 15-20kg or approx. 0.2g), known to lead to significant intervertebral disc loading on earth.

Through an ESA Space Medicine Team funded parabolic flight, the updated SkinSuit was found to be compatible with microgravity wear, including donning and doffing. In order to evaluate the efficacy of the SkinSuit, a novel model of microgravity, termed hyper-buoyancy floatation (HBF) was developed, which is able to induce significant spinal elongation to an extent greater than other ground-based analogues. HBF has now also been employed to evaluate muscle changes (and its markers) induced by offloading and represents a unique UK capability. HBF testing has allowed the team (PhD studentship funded by an ESA Network Partnering Initiative) to determine that donning the SkinSuit significantly reduces the tendency for the spinal column to elongate. Furthermore, in collaboration with the AECC University College, employing MRI and spinal fluoroscopy techniques the SkinSuit was shown to safely and effectively reload the spine, without impairing functionality.

During this research modification of a novel NASA ultrasonic technique was employed to evaluate intervertebral discs, both during HBF and subsequently artificial gravity loading, through short-arm centrifugation. This included during an 'ESA Spin Your Thesis' campaign and more recently by DLR as part of a GravityGym collaboration, which seeks to determine the feasibility and tolerability of candidate exercise modalities during artificial gravity to inform ESA's bed rest countermeasures research roadmap. The GLCS and SkinSuit have also been used to evaluate the role of changes in

(simulated) gravity on locomotion and motor control (PhD studentship funded by the EPSRC) – leading to an ESA programme of work called Movement in Low Gravity (MoLo).

This work has also led to the recent acceptance by ESA of both a short-duration in-flight ISS experiment evaluating intervertebral disc geometry and its relationship to stature and kinesiophobia (the reticence to move) in-flight, and a long-duration pre-post spaceflight experiment including MRI and measures of vertebral compliance with international collaborators.

The SkinSuit has flown in orbit on two occasions, during Andreas Mogenson's flight to the ISS to assess tolerability and subsequently on Thomas Pesquet's first long duration mission.

Impact and Terrestrial Benefit: Driving research and innovation

Low back pain is a significant burden globally, leading to reduced socio-economic activity, quality of life and wellbeing. The lumbar spine, is known to be highly sensitive to physical inactivity but also adapts to the diurnal rhythm of gravity loading/off-loading when rising from sleep and later returning to bed. Sub-optimal posture, wearing back packs, poor lifting/exercise technique can also lead to back pain and dysfunction.

By evaluating the SkinSuit and the general role that loading plays in modulating aspects of the spinal column, key insights are being gained to inform back pain management and locomotor rehabilitation/training, including SMART technologies in Space and on Earth.

References

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