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Perspective

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Preliminary considerations for accessible space missions for all

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As new space missions are being prepared, now is the time for accessible designs and approaches. In a workshop, we asked attendees to discuss the adjustments for people with disabilities in relation to the established barriers to human spaceflight. Potential challenges were grouped into medical, physiological, subsistence, and technical. These challenges and potential solutions will inform future space missions and the emerging and more diverse field of space tourism.

Traditionally, human spaceflight has involved the selection of astronauts who are highly trained, fit and without any impairment. Recently, the field has offered further opportunities for a more diverse pool of individuals, and the development of commercial spaceflight may accelerate this trend. For example, individuals with long-term conditions have already participated in spaceflight missions (https://www.brainandlife.org/articles/astronaut-rich-cliffords-journey-with-parkinsons-disease https://www.virgingalactic.com/jon-goodwin-astronaut-bio). In 2022, the European Space Agency (ESA) was the first space agency to recruit an astronaut (albeit a reserve astronaut) with a physical disability. In early 2025, this reserve astronaut was declared fit for a long-duration mission on the International Space Station (ISS). These new initiatives are focusing on the individual needs and adjustments for participants. Our work supports these initiatives, with a broader focus on different physical and sensory impairments and considerations for spaceflight[1]. In this context, the distinction between impairment and disability is crucial. *Impairment* is defined as any loss or abnormality in anatomical structure, physiological or psychological function. Impairment can be considered an objective definition of a problem with a structure or organ of the body. *Disability* is defined as any restriction or lack of ability (resulting from an impairment) to perform a function or an activity, often in relation to what is considered the norm for individuals. Although one can consider the impairment an objective variable, the amount of disability experienced by individuals depends not only on the impairment, but also on the environment and societal infrastructures, which affect the ability of performing specified activities. It could be suggested that society makes individuals disabled by not providing adequate aids and adjustments that allow full participation.

This is an exciting time in the aerospace field, as new missions are being prepared to reach the Moon and Mars, and new technologies and processes are being designed to support the next generation of astronauts. Given the current landscape, accessibility considerations could be implemented in all phases of astronaut recruitment, training and support, in order to increase accessibility for a more diverse astronaut population for short and long missions. With appropriate provisions addressing the environmental changes affecting the human body, the field could consider a wider variety of astronaut candidates (including those with a disability) and work towards more accessible solutions to make spaceflight for all. Furthermore, with astronauts saying that ‘when it comes to space travel, we are all disabled’ (Samantha Cristoforetti https://www.bbc.co.uk/news/science-environment-56072219), given the space environment’s impact on the level of disability experienced, our scientific hypothesis is that certain impairments may become less disabling in space or even advantageous. If a less ableist approach could be adopted in human spaceflight, the focus could shift from the disability to the abilities (paraphrasing Tim Peake https://www.ft.com/content/d2ac4c11-ed89-484f-9e08-115fd95013d3).

The work presented in this paper aims to report on our experience with space and disability experts working together to make spaceflight accessible. Through open and accessible discussions, we identified current unmet needs and considerations for astronauts with physical and sensory disabilities, considering the major barriers to human spaceflight[2]. By considering challenges before, during and after space missions, we propose considerations for the field to work towards accessible spaceflight.

Approach

We held a workshop (19th September 2023) for 55 people with disability, their families and carers, people involved with charitable organisations supporting individuals with disabilities, and those with an interest and established expertise in aviation and human spaceflight. The workshop organiser

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(first author) introduced the established barriers to human spaceflight, including space radiation, gravitational fields, isolation and confinement, distance from Earth, close or hostile environments[2]. As space radiation and altered gravity affect human physiological health more directly, their physiological effect was illustrated, with the caveat that physical impairments were more likely to be more immediately affected by altered gravity rather than radiation. Then, the categories of impairments identified by ESA for the Parastronaut feasibility project (now Fly!) were presented. The main considerations and differences between lower Earth orbit (with a focus on data available from the ISS) and planetary exploration were addressed. It was highlighted that limited physiological data on planetary exploration is available, with some data being available from human missions on the Moon, but no human data from Mars. Participants were invited to ask questions and provide feedback during this introductory phase. Then participants were asked to work in subgroups of 5–10 individuals and consider a physical or sensory impairment they could identify within the group and discuss the needs, adjustments, disadvantages and advantages of such impairment in relation to spaceflight and altered gravity. No specific direction was given on the impairment selected, although participants were invited to reflect on conditions that they were familiar with, or had a lived experience of. Here we report the discussion on the physical aspects, including physiological and medical considerations before, during and after spaceflight. In terms of *before* a mission, participants were asked to consider astronaut recruitment and training, but also the development of new aids, such as new spacesuits for accessible missions. In terms of considerations *during* a mission, participants were asked to reflect on the effect of gravity on the human body in terms of launch, re-entry and extended periods in microgravity, but also physical countermeasures and their accessible adaptations. Finally, participants were invited to consider the needs *after* a mission, in terms of acute physiological changes and longer-term recovery and rehabilitation.

Results and discussion

The challenges that emerged from the group discussions (Fig. 1) were classified into four larger categories: medical, physiological, subsistence, and technical. In this paper, the main considerations for each category are discussed and the relevant evidence is considered for further human space research.

Medical

Medical challenges include the main adjustments for the physical impairment and management of the condition. The first aspect to consider is the *pharmacodynamics* between multiple drugs in the space environment. Although the effect of spaceflight on how medications are absorbed, distributed, metabolised, and excreted is not fully understood[3–5], individuals with disabilities may require a multiple-drug regimen. In such cases, drug interactions may impact quality of life and the ability to perform certain tasks during training, potentially requiring adequate adjustments. Astronauts may require specific drug combinations to manage pre-existing conditions or adapt to space travel. Further attention should be paid to adequate storage and the assessment of drugs' shelf life. However, individuals who are already accustomed to complex medication regimens may be more adept at managing and adhering to these protocols in space, reducing the likelihood of errors or complications. A more diverse astronaut population may also require revisiting medical planning and contingency capabilities (including diagnostic, medication, or other medical supplies). These updates should be considered for existing platforms and incorporated into future system requirements and planning, to develop inclusive solutions from the outset.

The risk of *infections* and their reactivation increases in space[6–8] due to altered immune responses and potential exposure to drug-resistant bacteria[9]. Astronauts with disabilities may have unique vulnerabilities to

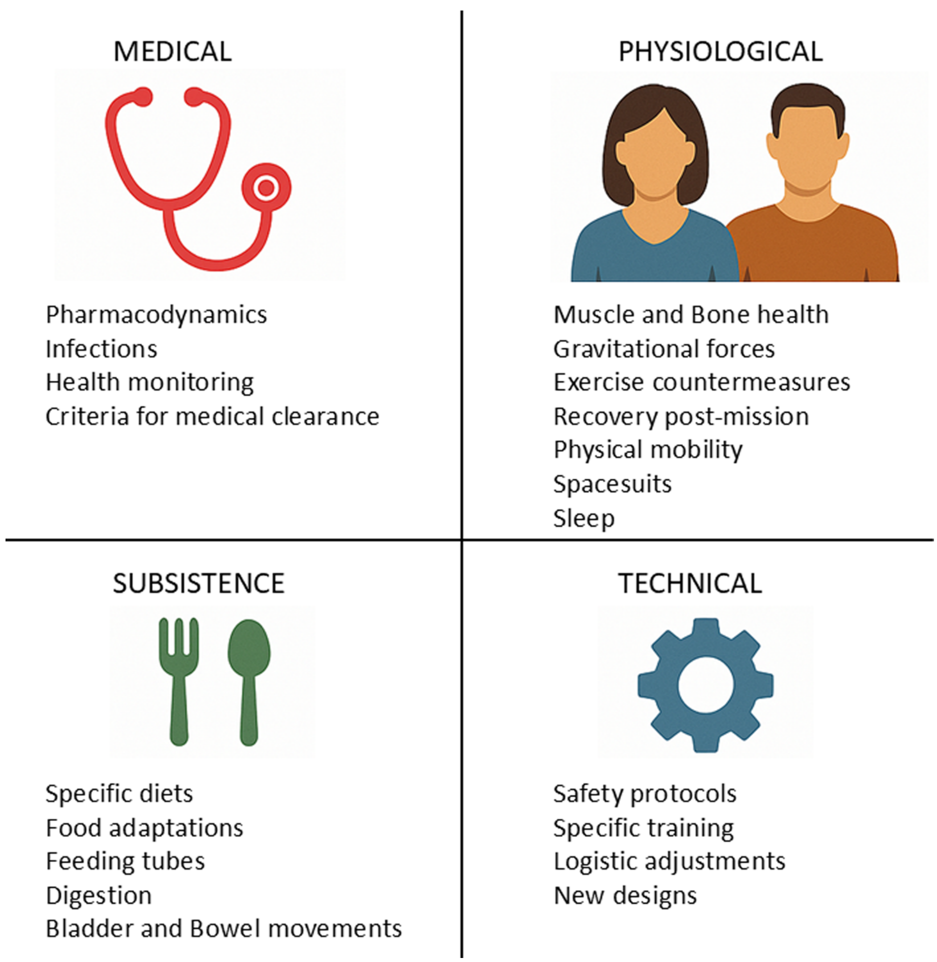

Fig. 1 | Concept figure summarising the four areas of discussion (categories) and the individual challenges that emerged within them.

infections, particularly if they have compromised immune systems. For example, since skin infections are the most common infections in spaceflight[10], and wound healing seems to be slower in space[11], hence individuals prone to wounds or skin conditions may require additional support. This is especially more relevant for those wearing mobility aids, like prostheses, as the stump may be a sensitive area and may become affected by different working loads in microgravity (e.g. unloading). However, those who have lived with chronic health conditions may be more experienced in managing infection risks, such as adhering to strict hygiene practices, recognising early symptoms, and effectively communicating with medical support teams. Their experience could enhance crew-wide infection control practices. Continuous *health monitoring* is crucial for all astronauts, but especially for those with disabilities who may need to detect and address medical issues promptly. Astronauts with disabilities may already use advanced health-monitoring devices, such as wearable sensors or telemedicine tools, and be accustomed to regular health assessments, making them well-prepared for continuous monitoring in space. This familiarity could reduce the learning curve and improve overall mission health management. In this respect, establishing *objective criteria for medical clearance* is essential to ensure both safety and inclusivity, without unconscious bias. Individuals with disabilities may have developed greater resilience, adaptability, and problem-solving skills from navigating environments that are not always designed with their needs in mind. This adaptability can be a valuable asset in space, where unforeseen challenges often arise, posing the need for creative and flexible responses.

It could be speculated that certain impairments could provide unexpected advantages in a space environment. For example, although additional storage needs for medications or time requirements for health monitoring may be needed, experience with pain management medications and symptom monitoring, in conditions like Multiple Sclerosis (MS) and diabetes, may allow for easier acceptance and adherence to health monitoring for the whole crew. These potential advantages can help optimise mission planning and resource allocation, allowing for a more inclusive and efficient approach to crew selection and health management.

Physiological

Physiological challenges focus on the body's response to the space environment, especially on muscle and bone wasting and on the effect of fluid shift towards the upper body. These effects of spaceflight on the human body are known, but the new frontiers of space exploration pose new questions regarding the human body responses, especially when considering long missions to Mars. However, the vast amount of data currently available is from a specific sample of participants, often with no/mild pre-existing conditions. This evidence from career astronauts is the foundation to understand and predict human adaptation to spaceflight in new missions. However, the data are a valuable source for new scientific enquiry into physiological mechanisms in other individuals, including those with impairments. By building on this existing knowledge, stakeholders can discuss new research and design new solutions for inclusive spaceflight. The goal for accessible spaceflight is to prevent long-lasting additional disability after a space mission.

When considering *muscle and bone health*, exposure to altered gravity affects their quality and homoeostasis[12–15]. Muscle weakness and fatigue are common in microgravity, and recovery[16] could be more prolonged for astronauts with pre-existing muscle conditions. Bone loss is common due to the reduced loads experienced by the body in reduced gravity[4,17–19]. Specific and personalised strength training and recovery protocols are necessary to ensure that astronauts with disabilities maintain muscle function and are prepared for the physical demands of space travel and their return to Earth. Early intervention and focused rehabilitation programmes post-mission could help facilitate quicker recovery and adaptation to Earth's gravity. The high *gravitational forces experienced during launch and re-entry* can pose significant challenges for astronauts, particularly those with muscle weakness or reduced cardiovascular capacity[20]. Adaptive measures, such as custom seating or restraints and training (including high-G acceleration exposure training), may be required to ensure these astronauts can tolerate such extreme conditions safely. Also, future deep-space expeditions will entail tasks conducted on planetary surfaces with reduced gravity levels, unlike the microgravity conditions experienced aboard the ISS. These missions will place increased physical demands on astronauts, requiring enhanced endurance and performance capabilities.

To reduce the negative effects of microgravity on the human body, a number of in-flight countermeasures are used, including a combination of exercise, diet and supplements[21–23]. These are currently under revision to be adapted for future missions, and at this stage, a 'design for all' approach is strongly recommended. In fact, *exercise countermeasures* are critical in space to counteract muscle atrophy and bone loss caused by prolonged weightlessness. For instance, to prevent neuromuscular and cardiovascular deconditioning, ISS crew members are prescribed a set of in-flight countermeasures comprising cycle ergometer, treadmill and resistive training (ARED) exercises[24]. Astronauts with disabilities may need tailored exercise programmes to maintain muscle strength and cardiovascular health. Customised equipment or modified routines could be necessary to accommodate individual needs. A potential benefit of some physical impairments includes less time required to train body regions or limbs that are missing or less functional, allowing for more efficient use of exercise time dedicated to maintaining overall health. Passive exercise techniques, such as electrical stimulation or venous or arterial occlusion devices, may be essential for astronauts with limited mobility or circulatory conditions. These methods can help promote blood flow and maintain cardiovascular health without requiring intense physical exertion. Adapting passive exercise regimens to the constraints of space travel could be required to mitigate some risks associated with reduced physical activity in microgravity, and these could benefit the whole crew. *Recovery time post-mission* may be longer for astronauts with disabilities, depending on their condition. Personalised rehabilitation plans that consider both the effects of microgravity and the astronaut's specific needs are crucial to ensure a safe and effective recovery process.

Microgravity may impact *physical mobility* differently for astronauts with disabilities. Those with reduced limb function or limited movement may find that weightlessness alleviates difficulties experienced on Earth, such as the strain of weight bearing on debilitated muscles or joints. However, moving through confined spaces and performing tasks in microgravity could require alternative mobility strategies or assistive devices to compensate for specific mobility limitations. Additionally, dressing in microgravity can be particularly challenging; thus, simplified garment designs or assistive tools could facilitate easier dressing procedures. *Spacesuits* must be modified to accommodate physical disabilities, ensuring that all astronauts can perform tasks comfortably and safely. Custom suits with altered entry points, enhanced manoeuvrability, and alternative pressure settings may be needed. Finally, *sleep disturbances* are common in space[25,26] due to changes in circadian rhythm, confined environments, and noise. Astronauts who use Continuous Positive Airway Pressure (CPAP) devices for sleep apnoea will require adaptations to these devices to function effectively in microgravity. Solutions like designing microgravity-compatible CPAP systems could help mitigate these challenges.

Interestingly, certain impairments may offer unexplored advantages in space. For instance, muscle loss is known to be most severe in the lower limbs, and one can hypothesise that those with bilateral lower limb amputations would not experience this negative effect. This has implications both whilst in space, where more time could be spent on exercising other muscle groups, and on return to Earth, where there would be no further muscle mass impairment caused by spaceflight. Another hypothesis is that individuals with vestibular loss may deal with gravitational transitions with fewer motion sickness and disorientation issues. Leveraging these unique physiological differences could optimise training schedules and reduce overall mission costs.

Subsistence

When considering subsistence (eating and digestion), the space environment can exacerbate pre-existing conditions. Astronauts may require *specific diets* to manage pre-existing medical conditions, such as low-sodium, high-fibre, or nutrient-dense meals. Space diets must be carefully planned to provide balanced nutrition while considering potential food allergies or intolerances. The body's ability to adjust to new diets in space may vary depending on the disability. Microgravity can alter taste perception, appetite, and nutrient absorption, requiring nutrition plans to ensure optimal health and performance throughout the mission. Microgravity requires specific *food adaptations*, in terms of packaging, preparation and consumption. Adaptations such as specialised utensils, easy-to-open packaging, and pre-cut bite-sized portions can make eating more manageable. Additionally, developing food products that are easy to handle and maintain consistency can help accommodate those with limited dexterity or fine motor skills. For astronauts who rely on *feeding tubes*, microgravity presents a unique set of challenges. Gravity usually assists in the flow of food and liquid through feeding tubes, but in space, this process requires alternative methods to create the necessary pressure. Adapted equipment, such as pressure-assisted feeding systems or manually operated pumps, may be needed to ensure the safe and effective delivery of nutrition.

Gravity plays a significant role in *digestion*, helping to move food through the gastrointestinal tract. In microgravity, the absence of this force can slow digestion, cause bloating, or lead to discomfort[27], which could be more pronounced in some astronauts, especially those with pre-existing conditions. However, the space environment can offer a surprising advantage for individuals with conditions that limit food motility on Earth **who** may find that reduced gravity alleviates some digestive discomforts related to posture or pressure on the abdomen. Managing *bladder and bowel movements* in microgravity is a challenge for all astronauts. Additional modifications to space toilets might be necessary to accommodate individual needs, such as catheters, ostomy bags, or other assistive devices. Regular monitoring and tailored protocols are essential to prevent complications, such as urinary tract infections or constipation, which may be exacerbated in altered-gravity environments.

Technical

Integrating astronauts with disabilities into space missions introduces various technical challenges that must be addressed to ensure safety, preparation, and accommodation for the entire crew. New missions and new astronauts require re-evaluating *safety protocols* to accommodate diverse needs. This may involve modifying emergency procedures, such as rapid evacuation protocols or rescue operations, to ensure they are effective for everyone[28]. While these adaptations could be seen as an additional challenge, they also present an opportunity to create more comprehensive safety measures that consider a wider range of scenarios, ultimately enhancing the safety of the entire crew. To work effectively as an integrated crew, *specific training* and performance assessments[29] are needed to understand and support various physical impairments. This preparation can include learning how to assist with mobility, operate adaptive equipment, or manage medical emergencies related to specific disabilities. Such training could foster a culture of teamwork, empathy, and resilience, which can strengthen the crew's overall cohesion and readiness to handle unforeseen situations during the mission. Accommodating different impairments also requires *logistic adjustments*, such as redesigning living and working spaces within the spacecraft or habitat to be accessible to all crew members. This might include installing handrails, optimising layouts for ease of movement, or developing modular and flexible designs to accommodate individuals with sensory impairments. While these modifications add complexity to mission planning, they can result in more versatile and ergonomic environments that benefit all crew members by improving accessibility, comfort, and usability. *New designs* are critical areas where technical challenges arise[28]. For example, spacesuits may need to accommodate prosthetics, limited mobility, or unique body shapes, and should allow for ease of donning and doffing in altered gravity. Entry and exit procedures for rocket capsules and habitats may require alternative methods, such as adjustable harnesses, assistive devices, or adapted procedures to ensure all astronauts can participate fully. These innovative solutions can improve the functionality and accessibility of equipment for all crew members.

Although an initial investment in terms of resources is needed, the process of accommodating astronauts with disabilities can drive innovation in technology and mission design. For example, developing more user-friendly interfaces, adaptable equipment, and inclusive environments can benefit everyone, making operations smoother and more efficient[30]. By including accessibility in system requirement documents and designing equipment, suits, and habitats that accommodate a range of abilities, space agencies and other stakeholders can create more versatile and adaptable systems. These designs might incorporate advanced robotics, smart textiles, or new materials that offer improved mobility, protection and functionality. The benefits of these advancements extend beyond space exploration, potentially leading to technological innovations that can be applied to assistive devices and mobility aids on Earth. Addressing the technical challenges of including astronauts with disabilities helps to make space exploration more inclusive and diverse. By demonstrating that space missions can accommodate people with a range of abilities, agencies can inspire a broader spectrum of talent to consider careers in space science and engineering, enhancing the pool of ideas, perspectives, and innovations.

Conclusions

This paper reports on our first workshop with disability and space experts. Most of the conversations reported here focused on addressing each challenge through an ability-based approach, i.e. emphasising the capability and the potential advantages of astronauts with physical or sensory impairments. This focus does not detract from the substantial challenges that emerged through this work. As new missions are being planned, involving all stakeholders is crucial. Accessible designs, solutions and processes could consider the main challenges outlined in this paper in order to address all needs. At this stage, new research is needed to test the hypotheses raised here and test new ones emerging from this work. By defining a priority list of challenges and impairments to be considered, a staged approach could drive the collection of rigorous scientific evidence to inform accessible spaceflight and rethink the assumptions regarding disability on Earth. A flexible and open-minded approach is essential to harness all available talent to support the new era of space exploration, including missions to the Moon and Mars, as well as the growth of commercial spaceflight and space tourism. We advocate for focussed and concerted efforts of the research community to address the points raised in this paper. Collaborative networks could address inclusivity to improve human spaceflight for all.

Data availability

No datasets were generated or analysed during the current study.

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Author contributions
I.D.G.: workshop organisation, delivery and discussion summary; ms writing. S.D.R.H., R.D.P., M.J.M.S., N.T.: workshop facilitator. All authors contributed to the design of the work and the discussion of the workshop findings. All authors reviewed the manuscript.

Competing interests
The authors declare no competing interests.

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