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Data-Gender Gap in Human Spaceflight: A New Frontier in Exploration

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Imagine developing an innovative car safety system. Armed with data from previous projects, you create detailed models, ensuring every component is optimised. To verify the system's robustness, you conduct extensive tests with a selected group of drivers. The results are promising—seat belts engage flawlessly, and airbags deploy with precision. Confident in your design, you launch the system for wider use. However, reports of malfunctions soon emerge: airbags fail to deploy properly, and seat belts fail to adequately protect certain drivers. Upon investigation, it becomes clear that the root issue lies not in flawed technology but in the limitations of the initial data. **By testing only on a homogeneous group of tall men, the system neglected the needs of diverse body types, making it unsuitable for others.**

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This analogy mirrors a profound issue in space research. For decades, health protocols, equipment design, and mission strategies have been predominantly based on data from male astronauts and cosmonauts. Like the flawed safety system, space exploration risks jeopardising astronaut safety by relying on incomplete data. The consequences became evident in 2019 when NASA's historic all-female spacewalk was postponed due to inadequate space suit sizes. Suits designed with predominantly male body dimensions in mind could not accommodate all female astronauts, underscoring the critical need for more inclusive data collection.

We are now at a turning point in the history of space exploration. Rapid technological advancements and expanding international collaborations promise a new era of exploration beyond Earth. However, to fully realise this potential, we must address the data-gender gap in human spaceflight. This gap extends beyond representation; it poses a fundamental barrier to ensuring all space travellers' safety, health, and mission success.

The lack of gender-specific data has even broader implications beyond space missions. Insights gained from space research often inform Earth-based medical studies, particularly in areas like osteoporosis, cardiovascular disease, and immune disorders—fields where gender differences are crucial. When data is skewed towards one gender, treatments and interventions developed for conditions that affect both men and women may be less effective for women, perpetuating disparities in healthcare. Just as a poorly designed safety system leaves drivers vulnerable, biased space and medical research can lead to misunderstandings that compromise the health and safety of diverse populations. To safeguard all individuals—whether in space or on Earth—we must prioritise comprehensive and inclusive data collection that accounts for the physiological differences across genders.

The Current State of Gender Data in Space Exploration

Historically, human spaceflight has been dominated by male astronauts and cosmonauts, with women representing only a limited fraction of those who have travelled to space. Since the beginning of human spaceflight in the 1960s, only about 12% of astronauts have been women. As of 2024, approximately 76 of the

650 individuals who had flown to space were women. This includes astronauts from governmental space agencies and private space travellers who have participated in suborbital and orbital missions, particularly with the rise of commercial spaceflight companies such as SpaceX, Blue Origin, and Virgin Galactic. While the number of female astronauts has increased slightly, this growth still highlights the significant gender disparity in human spaceflight. Notably, most of these female astronauts have participated in missions in recent decades, reflecting a gradual—though still limited—improvement in gender diversity in space exploration.

The gender disparity in space exploration is not just a matter of underrepresentation; it has far-reaching implications for the data collected and the knowledge we generate about how human bodies adapt to the unique challenges of space.

Key Gender-Specific Risks in Human Spaceflight

1. **Radiation Susceptibility**

Research suggests that female astronauts may be more susceptible to the health risks associated with space radiation. Women generally have a higher proportion of soft tissue and a different distribution of fat compared to men, which might affect their exposure to and absorption of cosmic radiation. Studies indicate that the risk of cancer from radiation exposure could be higher for women due to their longer life expectancy and potentially different cellular repair mechanisms. Furthermore, women's reproductive organs are more sensitive to radiation, raising concerns about long-term health risks, particularly related to reproductive health and increased susceptibility to breast and ovarian cancers.

2. **Cardiovascular Responses**

Female astronauts also exhibit different cardiovascular responses in microgravity compared to their male counterparts. Women may experience more significant orthostatic intolerance and more pronounced reductions in blood volume and heart rate variability. These differences can affect their ability to adapt to space and return safely to Earth's gravity. For instance, women tend to have lower blood pressure and different hormonal regulation, which can result in more frequent presyncope (dizziness or fainting) after spaceflight.

3. **Musculoskeletal Changes**

Both men and women experience bone density loss in space, but the effects may be more pronounced in women. Female astronauts are more susceptible to bone loss, a condition known as spaceflight osteopenia, due to hormonal differences and lower baseline bone mineral density. Women tend to lose bone density more rapidly than men during extended missions, potentially leading to increased fracture risk upon return to Earth.

4. **Fluid Retention and Space Motion Sickness**

Fluid retention and space motion sickness are additional areas where women may face unique challenges. Women experience more pronounced fluid shifts in microgravity, which can lead to symptoms like headaches, visual disturbances, and greater vulnerability to space motion sickness. The incidence and severity of these symptoms may vary by gender, with some studies suggesting that women are more prone to motion sickness due to different vestibular functions and hormonal influences.

5. **Renal Stone Formation and Immune System Function**

Both men and women are at increased risk for renal stones in space due to altered urinary chemistry, though women are more prone to certain types, such as struvite stones, linked to urinary tract infections. The immune response also changes in space, and while gender-specific data are limited, there is evidence that women generally have stronger immune responses on Earth, which might influence their adaptation to space environments.

6. **Exercise Physiology and Performance**

Women generally have lower aerobic capacity and muscle strength than men, which may affect their performance of tasks like extravehicular activities (EVAs). However, when fitness levels are matched, these differences diminish, suggesting that tailored exercise regimens and equipment could mitigate gender-specific limitations. This highlights the need for personalised training programmes that address the distinct physiological profiles of male and female astronauts.

7. **Reproductive Health**

Ultimately, the potential impacts of spaceflight on reproductive health remain an area of concern, particularly for women. The effects of space radiation and microgravity on menstrual function, retrograde menstruation, and overall reproductive health are not fully understood. There is also concern about how spaceflight might impact future fertility, with the unknown risks that radiation exposure poses to the ovaries and potential genetic implications for offspring.

The Importance of Gender-Disaggregated Data in Space Research

Optimising Spacecraft Design and Mission Planning

Spacecraft design and mission planning must take into account gender-specific needs to avoid critical oversights that could compromise safety and mission success. For example, designing spacesuits, workstations, and habitation modules that accommodate a wider range of body sizes and strengths is essential. Women, on average, tend to be smaller in stature and have different strength profiles compared to men, which can affect their ability to perform certain tasks, such as EVAs. As previously mentioned, NASA's early spacesuit designs were not well-suited for smaller body frames.

Incorporating gender-specific data in mission planning is equally important. Studies show that women may have different nutritional needs due to hormonal fluctuations and different metabolic rates, which affect the type and quantity of food and supplements required for long-duration missions. A failure to consider these differences could result in nutritional deficiencies or other health issues that impair performance. Additionally, women may require distinct medical supplies and protocols to address conditions such as urinary tract infections, to which they are more prone in microgravity.

Improving Life Support Systems and Habitat Environments

The design of life support systems and habitat environments must also be informed by gender-specific data. For example, differences in thermoregulation suggest that women may feel colder than men under the same environmental conditions, necessitating different climate control settings or clothing options to ensure comfort and prevent hypothermia. Furthermore, sleep patterns and circadian rhythms can vary between men and women, which could influence the design of sleeping quarters, lighting systems, and schedules that support optimal rest and recovery.

The psychological and social aspects of space travel also warrant consideration. Studies on space analogue settings on Earth, have shown that men and women may cope differently with the stresses of isolation and confinement during long-duration missions. Women may experience and express anxiety or depression differently from men, affecting both their mental health and group dynamics. Gender-disaggregated data can guide the creation of psychological support programmes that include gender-specific stress management strategies, mental health monitoring, and team-building activities that enhance crew cohesion and performance.

Advancing Research and Innovation

Finally, the collection and analysis of gender-disaggregated data can drive innovation in space research and technology. By understanding the nuanced ways that men and women respond to space conditions, researchers can identify new areas of study and develop novel technologies that improve safety, efficiency, and comfort for all astronauts. For example, wearable health monitoring devices capable of providing real-time feedback on vital signs could be customised based on gender-specific trends, offering more accurate assessments and earlier detection of potential health issues.

By incorporating this data into every aspect of space exploration, from spacecraft design to mission planning, health monitoring, and life support systems, space agencies can develop more effective countermeasures and protocols tailored to the needs of all crew members. This will ultimately lead to more successful missions, reduced risks, and a space exploration environment where all astronauts are equally prepared and supported to meet challenges.

Challenges in Collecting Gender-Sensitive Data

Despite its critical importance, collecting gender-sensitive data in space research is challenging. Historical bias represents a major challenge. As stated, much of the existing data on human adaptation to space environments comes from studies conducted during earlier missions, which predominantly involved male space travellers. This historical bias could affect current research frameworks and decision-making processes, perpetuating a cycle in which similar data is continually used to inform future missions and studies.

Another major barrier is the limited sample size. The number of female astronauts remains relatively low, making it difficult to gather statistically significant data *(to note: the limited number of male astronauts is also a limitation in space medical studies)*. This limitation is compounded by the high cost and logistical constraints of space missions, which restrict opportunities to conduct research with larger and more diverse astronaut cohorts.

Institutional barriers also contribute to the data-gender gap. Research agendas in space exploration often prioritise mission-specific goals over broader, inclusive studies. As a result, gender sensitivity is not always prioritised, leading to missed opportunities to collect valuable data.

Additionally, there are privacy and ethical concerns related to collecting data on gender-specific health issues, particularly those concerning reproductive health. For instance, studying the effects of space travel on menstruation, pregnancy, and hormonal cycles involves sensitive ethical considerations that must be carefully managed to protect astronaut privacy and dignity.

Research Directions

To bridge the data-gender gap in human spaceflight, a multi-faceted approach is necessary, encompassing inclusive research design, cross-sector collaboration, and the utilisation of emerging technologies. Each of these areas offers unique opportunities to address the gaps in our understanding of gender-specific responses to space environments and to create a more equitable framework.

Research Design and Cross-Sector Collaboration

Future research should deliberately incorporate gender as a key variable. This involves developing specific protocols to investigate gender differences in a range of physiological, psychological, and behavioural responses to space conditions, such as microgravity, radiation, and isolation. Cross-sector collaboration is consequently crucial for addressing the data-gender gap effectively. Space agencies, academic institutions, private companies, and international organisations should work together to share data, pool resources, and establish best practices for gender-sensitive research.

One approach could be the establishment of international consortia or partnerships dedicated to gender research in space. Such partnerships could coordinate large-scale studies that include diverse populations from multiple countries, enhancing the statistical power and relevance of the findings. Cross-sector collaboration could also extend to educational and outreach programmes designed to encourage women to pursue careers in space science, engineering, and astronautics. By fostering a diverse talent pipeline, the space sector can ensure that future research teams are more inclusive and better equipped to address gender-specific challenges.

Emerging Technologies

Emerging technologies offer significant potential to help close the data-gender gap. For example, artificial intelligence (AI) and machine learning algorithms can be used to analyse existing datasets for gender differences that may not have been previously recognised. These technologies can identify patterns and correlations across vast amounts of data, revealing subtle differences in physiological or psychological responses to space that traditional analysis might overlook.

AI can also be used to predict and model gender-specific health risks in space. For instance, machine learning models could analyse data from past missions to forecast how women and men might respond differently to specific conditions, such as extended exposure to microgravity or increased radiation levels. This information could be used to develop personalised countermeasures, such as tailored exercise protocols, nutritional plans, or pharmacological treatments, that mitigate these risks.

For instance, NASA's GeneLab project is a major effort that collects large-scale biological data from astronauts, including data on gene expression, proteins, and metabolites, to better understand how spaceflight affects different biological processes. GeneLab has started using AI and machine learning to analyse these vast datasets, with the goal of uncovering how space conditions uniquely impact men and women.
Another initiative is the Bio-Monitor, developed by the Canadian Space Agency (CSA), which is a wearable health-monitoring system designed to track an astronaut's vital signs in real time during space missions. The Bio-Monitor collects data on heart rate, blood pressure, temperature, and more, and this data is analysed to identify trends related to gender-specific physiological responses to space. By gathering continuous, gender-disaggregated data, the Bio-Monitor helps space agencies better understand how space conditions affect male and female astronauts differently.
Additionally, the European Space Agency (ESA) is using AI in collaboration with NASA's TRISH (Translational Research Institute for Space Health) to model the long-term effects of space radiation on both male and female reproductive health. These predictive models simulate how radiation impacts female reproductive organs, helping to fill the current gaps in data that largely focus on male astronauts.

These ongoing efforts demonstrate that space agencies are already harnessing the power of AI and machine learning to better understand the gender-specific challenges of space travel. These technologies are being used not only to close the data gap but also **to inform the development of personalised countermeasures for astronauts**, ensuring safer and more effective mission planning.

Policy Advocacy and Institutional Changes

Finally, there is a pressing need for policy advocacy and awareness to ensure that all aspects of space exploration are inclusive of diverse needs. International space organisations should mandate gender-sensitive research in their guidelines and funding criteria. This could involve creating specific funding opportunities for studies focusing on gender differences or developing new protocols for data collection and analysis that are sensitive to gender issues.

Shaping the Future of Space Exploration: A Call to Action

Closing the data-gender gap in human spaceflight is essential not only in terms of equality and fairness but as we saw, for enhancing the safety, effectiveness, and success of future missions. Achieving this requires a commitment to redefining our research priorities, challenging entrenched biases, and developing a deeper understanding of how space conditions impact all astronauts.

To build a truly inclusive future for space exploration, we must pursue rigorous, gender-sensitive research that reflects the diversity of those who will explore beyond Earth. By integrating these insights into every aspect of mission planning and design, we ensure that the next generation of explorers—regardless of gender—has the tools and support needed to succeed.